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Integration of Energy Consumption and CO_2 Emissions into the DES Tool with Lean Thinking

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Abstract. Products are often made by accomplishing a number of manufacturing processes on a sequential flow line which is also known as manufacturing systems. In a traditional way, design or evaluation of a manufacturing system involves a determination or an analysis of the system performance by adjusting system parameters relating to such as system capacity, material processing time, material-handling and transportation and shop-floor layout. Environment related parameters, however, are not considered or considered as separate issues. In the past decade, there has been a growing concern about the environmental protection and governments almost in all over the world enforced certain rules and regulation to promote energy saving and reduce carbon dioxide (CO_2) emissions in manufacturing industry. To date, development of a sustainable manufacturing system requires designers who need not merely to apply traditional methods of improving system efficiency and productivity but also examine the environmental issues in production of the developed manufacturing system. Most researchers, however, focused on operational systems, which do not incorporate the effect of environmental factors that may also affect the system performance. This paper presents a research work aiming to addresses these issues in design and evaluation of sustainable manufacturing systems incorporating parameters of energy consumption and CO_2 emissions into a DES (discrete event simulation) tool.

1. Introduction

Lean concepts are widely adopted by many manufacturing plants as a popular model when designing, implementing, operating or managing a manufacturing system. This is because it is a cost-effective approach promoting a sustainable manufacturing system by consistently seeking and removing any non-value added wastes in production without much additional investments. Lean thinking can also be described as an enterprise culture in which any creation of ideas or methods, which can be used effectively and economically for improving efficiency and productivity of a manufacturing system and reducing production costs, should be encouraged and embedded in any manufacturing-related activities or organizations. Manufacturing sustainability may be defined as the creation of manufactured products or systems by reducing the environmental impact on manufacturing systems due to usage of energy or natural resources. The conventional lean manufacturing method, however, does not consider environmental wastes of such as energy consumption and CO_2 emissions which are also considered as wastes of non-values added on manufactured products. Thus, to develop a sustainable manufacturing system, system designers need not merely to apply traditional methods to improve efficiency and productivity of a manufacturing system but also examine the environmental impact on the developed manufacturing system. This is also because governments in many countries have been enforcing ever-stricter environmental policies and regulations by promoting energy saving and low CO_2 emissions in manufacturing industry.

There are a few studies in considering environmental aspects related to developments of sustainable manufacturing systems using the modelling simulation methods. Heilala et al argued that manufacturing system designers need to not merely rely on traditional methods in improvements of system efficiency and productivity but also incorporate environmental considerations into design and operation of the developed manufacturing processes or systems [1]. Koc and Kaplan presented an investigation into energy consumption for a particular ring type yarn manufacturing system [2]. Lind et al developed a production simulation tool that was used for making a trade-off decision based on considerations of ergonomic constraints, levels of automation and environmental impacts [3]. Wang et al proposed the process integration (PI) method that was used for evaluating CO_2 emissions for a steel industry [4]. Gutowski et al conducted a thermodynamic analysis by examining the resources used in manufacturing processes [5]. Branham et al used the quantitative thermodynamic analysis for quantifying energy in different categories applied into manufacturing processes or systems [6]. Moreover, current modelling simulation tools in the market for manufacturing systems evaluation do not provide facilities that allow system designers to combine parameters of energy consumption and CO_2 emissions into an investigation of the overall manufacturing system performance. This is because, for example, in a discrete event simulation (DES) model, facilities are defined and treated as resources the same as parts, machines, conveyors and so on. The application of DES models is therefore restricted to predicting only such variables as the required number of workers, their shift patterns and routes [7]. This paper presents a study in mapping parameters relating to energy consumption and CO_2 emissions for manufacturing systems design and evaluation by proposing a methodology that can incorporate these parameters into the existing DES tools.

2. Energy Consumption and CO_2 Emissions for Manufacturing Systems Design and Evaluation

In a manufacturing system, energy is used for operating machines, illumination systems, air conditioning systems and other relevant supporting equipment such as compressors which supply compressed air to some of these machines. To describe amounts of energy consumption and CO_2 emissions mathematically, the following notations are used:

m: number of processes in a manufacturing system
n_i: number of machines involved in process i, where $i \in \{1, 2, ..., m\}$
E_i (kWh): energy consumption for a machine involved in process i
E_i^{cond} (kWh): energy consumption of an air conditioning system
E_i^{illum} (kWh): energy consumption of an illumination system
$E_i^{air\ comp}$ (kWh): energy consumption of compressed air needed for a machine involved in process i
TE (kWh): total energy consumption of a manufacturing system
N_i (kw): installed power for a machine involved in process i
R_i (kg/h): manufacturing rate for a machine involved in process i
τ_i (hr): operating time for a machine involved in process i
μ_i (%): efficiency for a machine involved in process i
∂_i (kg): mass of materials transferred from a machine involved in process i
G_i (kg): mass production per month
$¥_i$ (%): waste ratio for a machine involved in process i
$Ę_i$ (kWh): energy consumption of air conditioning per month
$Ě_i$ (kWh): energy consumption of illumination per month
$\zeta_i^{air\ comp}$ (kWh/m^3): energy consumption per cubic meter of a compressor
υ_i (m^3/h): compressed air used for a machine involved in process i per hour
$\rho_i^{air\ comp}$ (m^3/h): capacity of compressed air in cubic meter per hour of a compressor
$N_i^{air\ comp}$ (kWh): installed power for a compressor
e_i (kg/kWh): amount of CO_2 emissions per kWh released from a machine involved in process i
Te_i (kg/kWh): amount of CO_2 emissions per KWh of a machine, an air conditioning system and anillumination system involved in process i

ω : CO_2 emission factor using different energy sources
Te (kg/kWh): total amount of CO_2 emissions released from a manufacturing system
q_i (kg): mass of materials involved in process *i*

2.1. Energy Consumption

The energy consumption E_i for a machine involved in process *i* is given by:

$$E_i = \tau_i \times N_i \times n_i \tag{1}$$

The operating time τ_i for a machine involved in process *i* is calculated by:

$$\tau_i = \frac{q_i}{R_i \times \mu_i} \tag{2}$$

Mass of materials q_i transferred from a machine involved in process *i* is obtained by:

$$q_i = \partial_i \times (1 + ¥_i) \tag{3}$$

The energy consumption for air conditioning E_i^{cond} in a manufacturing system is given by:

$$E_i^{cond} = Ȩ_i \times \frac{\partial_i}{G_i} \tag{4}$$

The energy used for an illumination system E_i^{illum} is calculated by:

$$E_i^{illum} = Ě_i \times \frac{\partial_i}{G_i} \tag{5}$$

The energy consumption of a compressed air needed for a machine involved in process *i*, thus $E_i^{air\ comp}$ is calculated by:

$$E_i^{air\ comp} = \tau_i \times \zeta_i^{air\ comp} \times \upsilon_i \times n_i \tag{6}$$

Where $\zeta_i^{air\ comp}$ can be determined by:

$$\zeta_i^{air\ comp} = \frac{N_i^{air\ comp}}{\rho_i^{air\ comp}} \tag{7}$$

Thus, the total energy consumption TE for a manufacturing system is given below:

$$TE = \sum_{i=1}^{m} (E_i + E_i^{air\ comp} + E_i^{cond} + E_i^{illum})$$

Where $i \in \{1, 2, \ldots, m\}$ (8)

Hence, equation 8 can be given below:

$$TE = \sum_{i=1}^{m} \left(\frac{\partial_i \times (1 + ¥_i)}{R_i \times \mu_i} \times N_i \times n_i + \tau_i \times \zeta_i^{air\ comp} \times \upsilon_i \times n_i + Ȩ_i \times \frac{\partial_i}{G_i} + Ě_i \times \frac{\partial_i}{G_i}\right) \tag{9}$$

2.2. CO_2 Emissions

The amount of CO_2 emissions e_i released from a machine involved in process *i* is calculated by

$$e_i = \omega \times E_i \tag{10}$$

Where, the value of CO_2 emission factor ω is given in Table 1 [8].

Table 1. CO_2 emission factor ω (per kWh) using different energy sources

Energy source	ω (kg/kWh)
Oil as direct energy source to generate thermal energy	0.5
Oil as indirect energy source to generate electricity	0.6895
Solar as indirect energy source to generate electricity	0.05

The total amount of CO_2 emissions *Te* can be calculated as follows [9]:

$$Te = \sum_{i=1}^{m} (e_i \times q_i + 0.6895 \times (E_i^{air\ comp} + E_i^{cond} + E_i^{illum}))$$

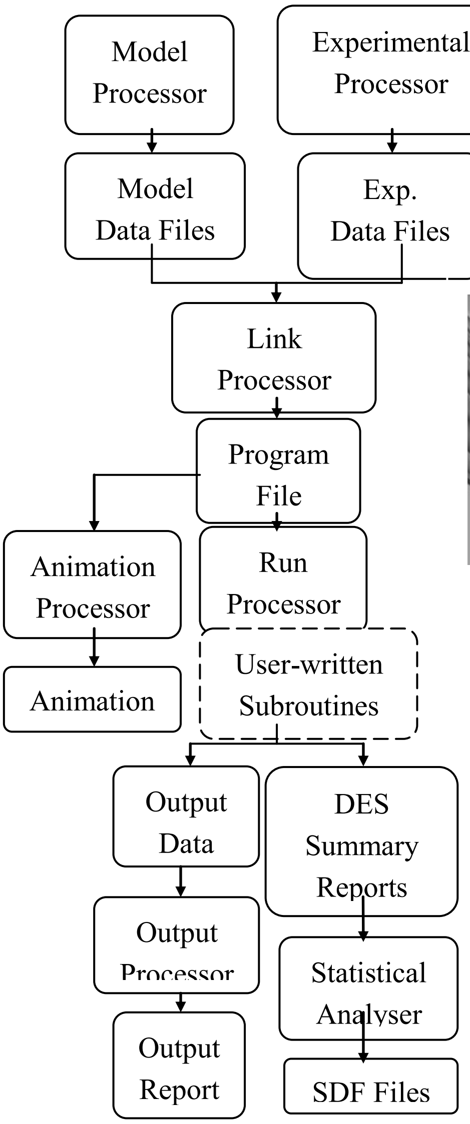
Where
$$i \in \{1, 2, \ldots, m\} \tag{11}$$

Thus, Te can be expressed below:

$$Te = \sum_{i=1}^{m} (\omega \times \tau_i \times N_i \times n_i \times \partial_i \times (1 + ¥_i) + 0.6895 \times (\tau_i \times \zeta_i^{air\ comp} \times \upsilon_i \times n_i + Ę_i \times \frac{\partial_i}{G_i} + \check{E}_i \times \frac{\partial_i}{G_i}) \tag{12}$$

3. Implementation of Energy Parameters into a DES Tool

Until recently, there has been a lack of feasible and practical modeling simulation tools which permit system designers, at the early design stage, to assess the performance of manufacturing operations by taking the environmental aspect into account within manufacturing systems. For instance, discrete event simulation (DES) tools are widely used for manufacturing systems design and evaluation, and these modeling simulation packages have now evolved from 2D to 3D. Nevertheless, these tools do not have built-in functionalities that allow system designers to evaluate the performance of manufacturing systems by incorporating considerations of such as energy consumption and CO_2 emissions relating to manufacturing activities within a manufacturing system. In order to resolve this, parameters of energy consumption and CO_2 emissions can be modeled into either external MS Excel worksheets that can be linked into a DES tool or internal program using the DES simulation language; these parameters interact with parameters of physical elements (built in the DES tool) of machines and conveyors etc., together with logical interrelationship for operational activities in a manufacturing system. With this approach, by altering a value of each parameter of energy consumption and CO_2 emissions, this enables system designers to evaluate the overall performance of a manufacturing system considering not just operational activities bus also amounts of energy consumption and CO_2 emissions that are generated for running manufacturing facilities and processes. This integrated modeling simulation methodology also permits users to determine the relevant impact on logical interactions and interrelationships between parameters in manufacturing operations, energy consumption and CO_2 emissions within a manufacturing system. With the integrated approach, a manufacturing system can be modeled, simulated and examined concurrently to gain a comprehensive preview of the system performance and provide the performance prediction that allows designers to build a system based on an optimal solution before implementing a real system. Moreover, this technique can be implemented as a strategic planning tool for systems analysts and designers to quickly provide a visible preview of the integrated system performance at an early stage in the design process. Figure 1 illustrates an integrated DES model with which a manufacturing system design can be investigated aimed to minimize unnecessary wastes of materials handing activities by implementing lean management rules and reduce the environment impact of energy consumption and CO_2 emissions.



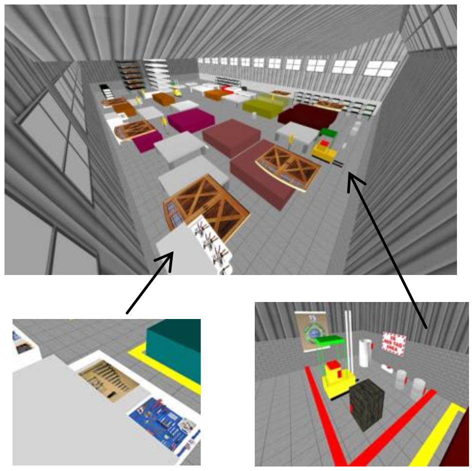


Figure 1. Integration of energy consumption and CO_2 emissions into a DES model for modelling and simulation of a lean manufacturing system

4. Conclusions and Future Work

When designing a manufacturing system, engineers used to focus on key performance indicators in terms of such as system productivity, capacity and other operation-related issues; environmental considerations are often overlooked or considered separately. Moreover, a literature study by authors shows that there is a lack of DES modeling simulation tools for manufacturing systems design and evaluation by combining parameters associated with environmental considerations of such as energy consumption and CO_2 emissions. This paper presents a study in proposing an integrated DES model by addressing energy consumption and CO_2 emissions relating to manufacturing activities of manufacturing systems. The proposed DES tool has capability of incorporating a number of environmental parameters in terms of energy consumption and CO_2 emissions allowing a joint analysis of a manufacturing system performance under environmental constraints. The integrated method can be useful for helping decision-makers to develop a manufacturing system considering amounts of energy consumption and CO_2 emissions. In the latest developments of DES tools, although developers have been slowly introducing cloud-based technologies to facilitate the mobility of applications and the interoperability between different users or partners, none of these DES tools has built-in functions incorporating parameters of energy consumption and CO_2 emissions for manufacturing systems design and evaluation. Apart from this, current DES tools have a lack of a great variety of functions and data exchange among different domains which cause difficulties in interoperability and collaboration between systems or users. These issues ought to be addressed in the future development with utilization and integration of multi-disciplinary and multi-domain simulation tools. Through the literature studies, there were a few studies in product life-cycle costs relating to environmental issues that were incorporated into DES tools. As a result, simulation tools that assure the multi-level integrations are still under developments. Also, efforts ought to be made to create smart, intelligent and self-learning DETS tools. Research is required in order to develop more intelligent tools that will lead to autonomous and self-adapting systems for automated optimization of system parameters [7].

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