Ralph Stelzer · Karl-Heinrich Grote · Klaus Brökel
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ENTWERFEN ENTWICKELN **ERLEBEN**

Methoden und Werkzeuge in der Produktentwicklung

10. Gemeinsames Kolloquium Konstruktionstechnik
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TUD*press*

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LCA to support decision-making in layout designs

1 Introduction

The economic impact of environmental regulations in the manufacturing sector and the increasing costs of primary resources have pressured companies wishing to obtain competitive advantages to seek ways to rationalize these resources, either through changes in products specifications or in manufacturing process. These actions depend on solutions that should consider the limits set out in the interdependencies between economic, environmental and social areas, which comprise the so-called sustainability tripod. In this case, the guiding principle for decisions should follow the approach of sustainable development. For this purpose, a proper performance indicators evaluation of processes is a great step to improvement actions and decision making for modifications. Continuous improvement approaches and support of mathematical tools, such as the Discrete Event Simulation (DES) have been used for identifying waste on the shop floor and for cost analyses for manufacturing optimization (Standridge et al. 2006). One of the advantages resulting from the application of DES in corporations is its capability to include the impact of randomness in a system. All the dynamics and the non-deterministic nature of the parameters eliminate the use of static tools such as spreadsheets for solving many line design problems. Furthermore, all commercial simulation software provides detailed animation capabilities. The animation of the manufacturing process and flow can help engineers to visually detect problems or bottlenecks and also to test out alternate line designs. For this reason, the DES may be applied to generate requirements and sustainable systems specifications for manufacturing. However, the analyses results performed by using DES are not sufficient for the joint assessment of impacts on the three dimensions of sustainability (Johansson et al. 2010; Kuhl & Zhou 2009; Joschko et al. 2009).

A tool widely used in the academic environment and by corporations to calculate pollutant emissions rates in the product life cycle is Life Cycle Assessment (LCA). This can supplement cost assessments performed with DES in the production process phase.

This work discusses the combined use of DES with LCA to analyze production resources utilization in manufacturing systems. Towards this end, it seeks through a case study to analyze this joint use in decision-making for purchasing forklifts, according to sustainable premises.

2 Analysis for Sustainable Manufacturing

There are distinct tools and techniques to analyze and provide environmentally sustainable manufacturing systems. In most cases, consisting of cost analysis integrated with pollutant emissions analysis (Joschko et al. 2009; Johansson et al. 2010; Helu et al. 2010; Hermann et al. 2011). One of the biggest challenges for projects of new production systems is in obtaining data for the environmental impacts analysis, incorporated into the typical analyses of production (production capacity, material flow, transport, occupation rate of posts, etc.). The following topics introduce two evaluation methods for this type of analysis.

2.1 Life Cycle Assessment

In an LCA study is possible to develop a systematic analysis of the environmental consequences associated with products during their lifecycle The most significant application of LCA concerns to support the decision-making in areas such as innovation, regulations (industrial, environmental), strategies and policies.

LCA consists of a four-stage process: Goals and scope definition; Inventory analysis (LCI); Impact assessment (LCIA); and results interpretation. LCA only permits to assess potential environmental impacts from different types (air pollution, land use, toxicity). LCIA aims at converting flows into potential impacts (midpoint) and consequences or effects (endpoint).

The biggest limitation of LCA studies as a tool for sustainability is that its environmental impacts only covers standard, not considering economic and social aspects (Silva 2010). The cost aspect is being integrated to LCA through liaisons with the life-cycle cost (LCC- Life Cycle Cost), that considers the cost implications originated in the entire product life cycle (Haggar 2007).

2.2 Sustainability Analyzes with Discrete Event Simulation (DES) method

The development of a computer program is just one of the many activities of a simulation process. In order for this to be successful, other activities should be followed. This set of activities or process is known in the literature as a methodology of simulation or life cycle of a simulation model (Banks et al. 2001).

By means of a computer simulation is possible to check some peculiar characteristics of a production floor as: the lead-time, identifying resources capacity constraints, the verification time of use rates of workers and machinery, the physical space required and the production volume variance (Kuehn 2006). Automotive companies have increasingly used the simulation as a prominent decision support tool. Most makes use of DES to model manufacturing systems and to analyze issues relating to the factory layout, process flow, material handling systems, capacity planning, investment in new equipment and production scheduling and logistics as well (Kuehn 2006).

There are many other criteria, which one could measure with DES besides to support production profitability improvements. Environmental considerations are becoming more relevant and require greater attention. DES with LCA is one possible combination for analyzing the cause and effect of various scenarios where time,

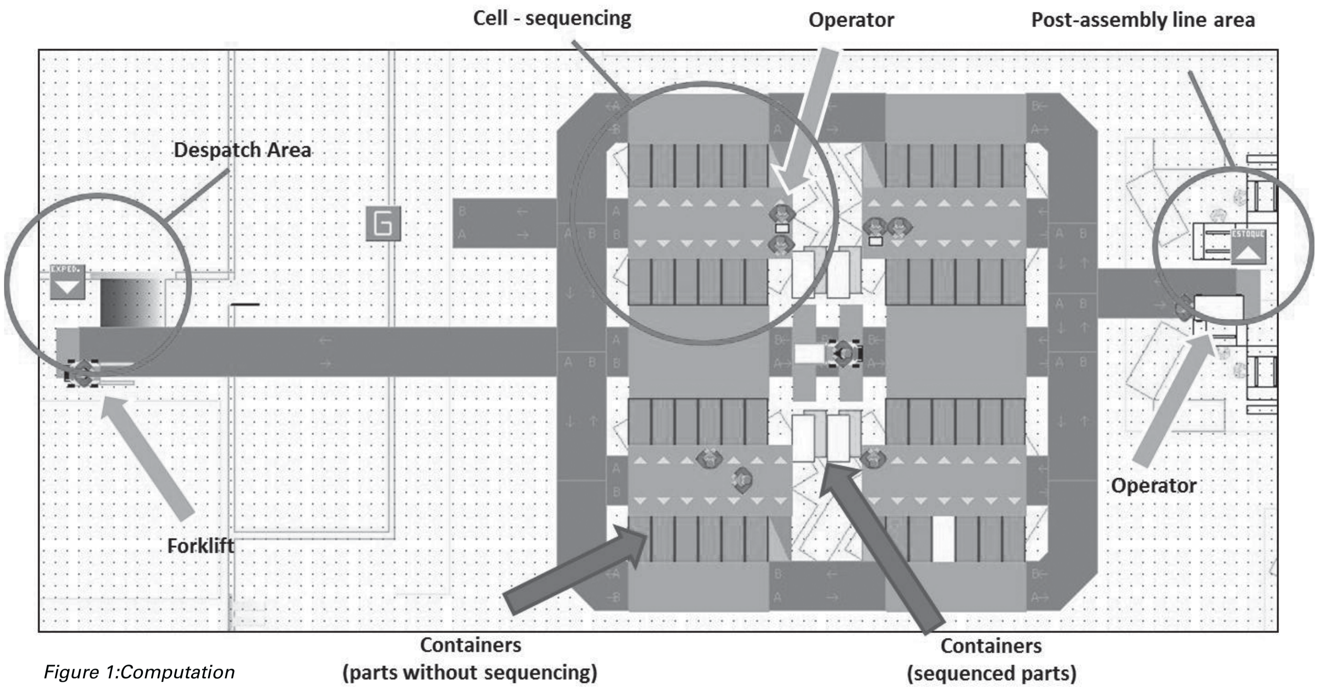

Figure 1:Computation model with 4 operators and two forklifts

resources, place, and randomness of input variables affect the outcome in sustainable manufacturing design.

This joint application establishes the dynamic environment for sustainable production systems assessments and is an unexplored area with a few research publications. The few examples include: Solding and Petku (2005) and Solding and Thollander (2006). Both describe how DES could be utilized to reduce electricity consumption for foundries. Johansson et al (2009) describe how DES could be utilized in combination with LCA for decreasing environmental impacts during food production (Johansson et al. 2009). Also Kuhl & Zhou (2010) describe LCA with DES applied to logistics developments.

3 Case Study

The case study verified a joint application of LCA with DES to support the decision making to purchase manufacturing facilities, considering costs and greenhouse gas emissions. For this purpose was analyzed a sequencing process layout involving automotive door panels. From data input process, computational models were developed and different scenarios proposed were simulated.

The simulation results have shown the number of forklifts and operators needed to meet production requirements and also the covered distances by forklifts. At the end of the case study was possible to determine the best layout and the forklifts type being used.

3.1 System Description

The model is a supermarket product with 504 m2 area. The products are automotive door panels, sequenced by the operators according to the customer's orders, and transported by forklift trucks until the dispatch sector.

Computational models have been developed for the manufacturing system. It has four sequencing cells. Each cell has twelve containers overlapping with panels out of sequence from the assembly line, arranged in six sequenced pairs, and two containers with already sequenced panels, also overlapping.

	Cells amount	Operators amount	Forklifts amount
Scenario 5	4	8	1
Scenario 6	4	8	2
Scenario 7	4	4	1
Scenario 8	4	4	2
Scenario 9	2	4	1
Scenario 10	2	4	2
Scenario 11	2	2	1
Scenario 12	2	2	2

Table 1:Simulated Settings

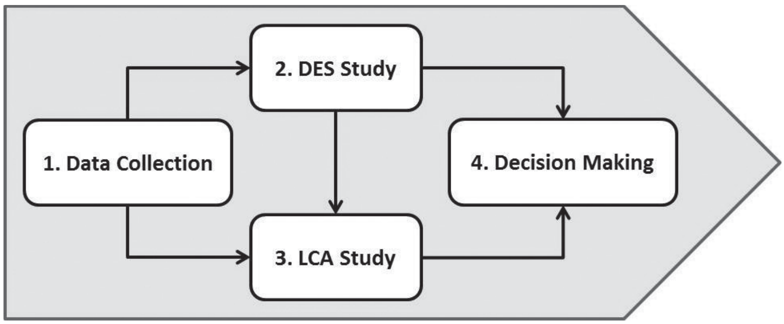

Figure 2: Experimental Planning

Figure 1 illustrates the computational model, with two operators per cell and two forklifts. For the production behavior analysis were simulated different settings, ranging from the number of operators, forklifts and cells, according to table 1. For computational modeling and simulation it was used the software Plant Simulation by Siemens.

3.2 Experimental Planning

The case study was implemented, according to the four stages presented in Figure 2: Data collection; DES study; LCA study and decision making. The process data were acquired in step 1. From these data, computational models were developed in step 2. In parallel with results supplied by the simulation analyses was conducted in step 3 a Life Cycle Assessment to verify the use of forklifts with different energy sources. The results from these two methods supported the decision making for the acquisition of forklifts.

3.2.1 Data Collection

The data collection corresponds to the entire process of data input modeling and computational model formulation.

Most systems have some random phenomenon that governs. For these cases, input data modeling consists in defining probabilistic models. In a production system with machines and operators, an important random phenomenon is related to the handling time of operators and transporters. For cases where there is no way to collect data, either consult databases, deterministic data are used (Banks et al., 2001).

The case study presented corresponds to the layout designs phase. Thereby were considered deterministic data for material handling acquisition, for movements by operators and forklifts and for loading and un-loading by forklifts. Data for the life-cycle emissions analyzes were taken from Technical Report the JLCA and Energetics Incorporated of the United States.

3.2.2 DES Study

A simulation study begins with the definition of its goals. For this case study, the settings goals were verify: the production resources work rates; the production resources amount needed for the production of 380 containers sequenced per day; the distances travelled by forklifts. Later, conceptual models were constructed. A conceptual model was created with data collected from the production system, such as layouts, production flows, sequence diagrams, amount of machine and operators, speeds from machines and operators, shifts calendars and paths. The model only contained resources used for producing its components. Other production resources were not included.

The verification of the DES model was made continuously by studies of critical processes in the actual production and comparing them with processes in the model. Production data such as lead times from the model were compared with real times from the production for validation purposes.

The simulation results are presented in table 2, in accordance with the pre-established objectives. This table presents the results to the best observed scenarios for a period of one month and contains a comparative analysis of costs, according to the premise of production of 380 containers per month. In this first moment, the highest scoring regarding productivity and cost was obtained by scenario 7, with four sequencing cells, four operators (1 per cell) and one forklift performing the transport of containers. The distance travelled values are also data input for LCA analysis.

3.2.3 LCA Study

Figure 3 presents the results of a LCA study where the Global-warming potential (GWP) is observing in the comparison between electric and diesel forklifts.

Scenarios		Operators Amount	Forklifts		Containers (Qtd)	Cost (x$)	Score
			Amount	Covered Distance [km]			
4 Cells	S5	8	1	2210	610	77400	68,3
	S6	8	2	1376	1150	104400	95,3
	S7	4	1	2031	603	52200	100
	S8	4	2	1185	783	79200	85,6
2 Cells	S9	4	1	2138	571	52200	94,8
	S10	4	2	1087	682	79200	74,6

Table 2: Simulation results

The usage phase of forklifts highlighted in the Figure 3 is of greatest environmental impact factors within its life cycle. This high rate is directly related to the fuel consumption. In this way, the main factor to materially influence the choice of layout in forklift used must be the type of fuel used.

In Figure 4 there is a comparison of five types of fuels used by forklifts, listing their environmental impacts due GWP. This is displayed in metric tons CO2 equivalent per unit per year: Electricity, LPG (Liquefied Propane Gas), CNG (Compressed Natural Gas), Diesel and Gasoline. When these fuels are compared with the LPG, it appears that the Electricity has the lowest impact (-18%). On the other hand the Gasoline has the most impact, (+24%). The difference between CNG and Diesel is very small, being +1.4% and +2.8% respectively. It should also be noted that Diesel has a particulate matter (PM) issue that, when suspended in air, is harmful to human health. This makes the use of this fuel in forklifts working indoors or with low ventilation unfeasible.

3.2.4 Decision Making

In this step was considered the simulation results, presented in table 3, and analysis of fuel use in forklifts, discussed in figures 3 and 4. It is noted that the Scenario 7 has shown the lowest monthly cost, with the best relation cost/productivity among the scenarios evaluated. In addition, your daily productivity can be increased by up to180 containers/day (29%) with the addition of an extra forklift (moves to the scenario 8). This option provides flexibility in the case of an increase in demand. Due to these factors, the scenario 7 is recommended as the best alternative. The Scenario 7 also has shown the lowest travelled distance by forklift (2.031 km/month) which will result in lower fuel consumption and, consequently, into a smaller environmental impact.

For decision-making related to the fuel be used in forklifts noted that the electricity would be the best choice, followed by the LPG and CNG.

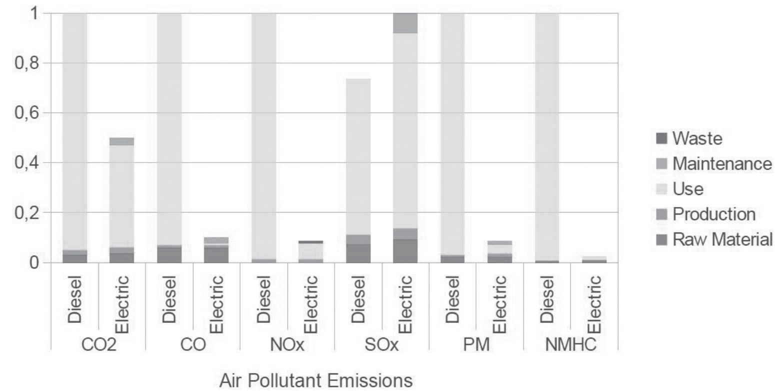

Figure 3:Analysis of GWP to forklifts, electric and diesel (Suzuki 2006)

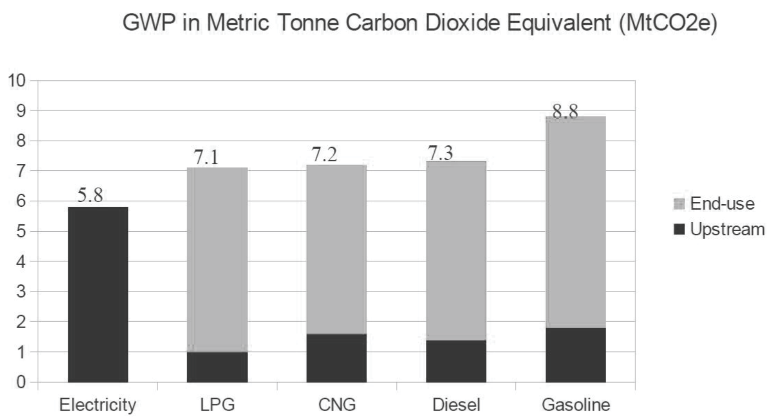

Figure 4:Comparison of fuels used by forklifts (Antes et al. 2007)

4 Conclusions and Prospects

The combined use of DES and LCA presents as a dynamic evaluation process to analyze production resource in manufacturing systems. In the case study presented in this paper, simulation output data, as distance travelled, could be compared with LCA studies of forklift fuels and to support the decision making to choose the type of forklift, according to sustainable premises. The best scenario related to the cost has also shown the smaller environmental impact. Thus it was not necessary to use results from LCA studies as input data in others computational models.

Further work in this area will be made so that the relationship between these two analysis methods to be exploited in work with greater interaction in the relation cost/environmental impact. In these cases, the output data from LCA will be input data for DES.

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