Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 29 (2015) 92 – 97

www.elsevier.com/locate/procedia

The 22nd CIRP conference on Life Cycle Engineering

Hierarchical modelling of complex material and energy flow in manufacturing systems

Samira Alvandi *, Georg Bienert, Wen Li, Sami Kara

Sustainable Manufacturing and Life Cycle Engineering Research Group
School of Mechanical and Manufacturing Engineering, University of New South Wales, Australia

* Corresponding author. Tel.: +61-02-9385-6851; E-*mail address:* samira.alvandi@student.unsw.edu.au

Abstract

Over the past decades, the economic and environmental soundness of manufacturing systems are often questioned because of the large consumption of energy and primary materials. In order to investigate potential opportunities towards achieving the material and energy efficiency in these systems, it is essential to model these flows and associated complexity in detail. An isolated consideration of individual processes which in themselves are comprised of sub-processes is not a sufficient approach. To obtain a reasonable level of detail from the system, hierarchical structure of energy and material consumers in the system is required.
In this paper a simulation based approach is presented to model energy and material flows. This approach considers hierarchical structure of energy and material consumers within the system. It can be served as a base to identify hotspots and to assess the effectiveness of retrofitting exercise through what-if scenarios. An industrial case study is used to demonstrate the applicability and the validity of the proposed approach.

Peer-review under responsibility of the scientific committee of The 22nd CIRP conference on Life Cycle Engineering

Keywords: *Energy and Material Efficiency, Simulation, Hierarchical Modelling, Retrofitting, Manufacturing Systems*

1. Introduction

Manufacturers today face many challenges to stay in the business. The trend among the manufacturers is now to seek opportunities to improve the efficiency of the material and energy and shift to environmentally benign practices. Some of the major forces that drive this shift are: steady increase in costs of energy and resources, risks associated with availability of material and energy, government regulations in reducing the environmental impacts of production.

Most of manufacturing systems involve complex, dynamic systems which consume energy, water and raw materials. Inefficiencies in these systems result in excess consumption of resources leading to increased costs and environmental footprint. Through an understanding of these inefficiencies, improvement opportunities can be identified and strategies can be developed to effectively lower costs and carbon footprint. In general, improvement opportunities and practices with respect to material and energy consumption within manufacturing systems can be generated over a wide range from a single machine to an entire factory. Some of these opportunities may involve adaptation of a new technology or retrofitting of the machine components [1] and [2]. Some other improvements focus on operational level and involve resource conscious production, and multi-objective process planning [3] and [4].

In order for management to decide what improvement strategies to initiate and at what scale and organisational level, it is first essential to understand the system inefficiencies and characteristics of the responsible elements in relation to material and energy usage. Common practice for the evaluation of the material and energy efficiency is through detailed breakdown and modelling of the energy and material usage within a manufacturing system. Few techniques and frameworks have been introduced for modelling the energy flows and associated environmental and economic impacts

Peer-review under responsibility of the scientific committee of The 22nd CIRP conference on Life Cycle Engineering
doi:10.1016/j.procir.2015.01.023

within the manufacturing systems [5], [6], and [7].

From the organization of the manufacturing systems perspective, manufacturing activities can be considered as being composed of at multiple levels[8]. It is also important to note that the choice of system abstraction levels depend on the goal of the research and on the specific question it addresses. Within the literature [9] and [10] focused on unit process levels and energy load profiles of single machines. There also exist several examples of process chain level modelling with reference to cumulative load profile of all the machines [11]and [12].

Environment-oriented software tools have been developed through the years in support of environmental impact studies. Life cycle assessment software tools like Umberto® are used in modelling the hierarchical structure of the material and energy flow. These tools allow for material and energy flows to be viewed from department level down to an individual process level. While simple top-down account of system's input-output flows is essential- as a starting point for modelling the aggregated flows in the entire system- the hierarchical modelling is still prone to limitations. They lack the ability to model the dynamic and complex systems. Because of the static nature of the existing LCA methods, the complex interdependencies between the hierarchical levels and time dependent flows cannot be captured. Some researchers have developed simulation models to address the time dependency and complexity of the energy flows and the associated environmental impact in the manufacturing systems. [13] utilises LCI (Life Cycle Inventory) data and performs static calculation of environmental metrics on the simulation results; therefore dynamic environmental assessment is still not achieved.

The emphasis of this paper is particularly on evaluation of the manufacturing system performance and the impact of machine component change and retrofitting. Current modelling efforts consider the horizontal interaction between machines and their corresponding dynamic flows or at best consider vertical and dynamic interactions between levels but with not enough details. Obviously there is a gap in literature for dynamic evaluation of the improvement strategies on the machine component level in relation to different levels of the manufacturing system's hierarchy. Therefor this paper proposes a hierarchical system modelling method through simulation. In section 2, the modelling framework and associated simulation model are presented. The applicability of the proposed model is verified through an industrial case study in section 3 followed by what-if-scenario exercise through simulation. In section 4, the simulation results and future work will be discussed.

2. Hierarchical simulation modelling of energy and material flows

The approach proposed in this paper is an extension of the previous framework reported by [14].As mentioned in previous section , the system break down in modelling manufacturing systems is highly motivated by the goal of the study. In order to fulfil the requirements of the current study on machine retrofitting, an additional level (Component Level) to the previous framework is considered. On this base, this paper proposes a hierarchical framework for modelling energy and material flows within manufacturing systems in four levels (Figure 1).

A bottom- up approach in the modelling of the manufacturing system starts from the bottom of the hierarchy. First the unit process level which represents the individual machine is characterized and modelled. Since the machine is a complex system in itself and consists of sub-components, further decomposition is applied on the machine level that results in the modelling of the component level. Thus machine component level is embedded within the unit process (machine). By linking the unit processes; process chains on the third level are composed. In multi-product manufacturing systems, different products can have different process chains and follow different routing.

The top of the hierarchy - Factory level - the technical building services such as compressors, central cooling and other departments responsible for production planning & control are modelled. The bottom up approach integrates the energy and material input-output flows within lower abstract levels to the upper levels. The controls and improvement strategies are propagated from Factory level to sub-ordinate levels.

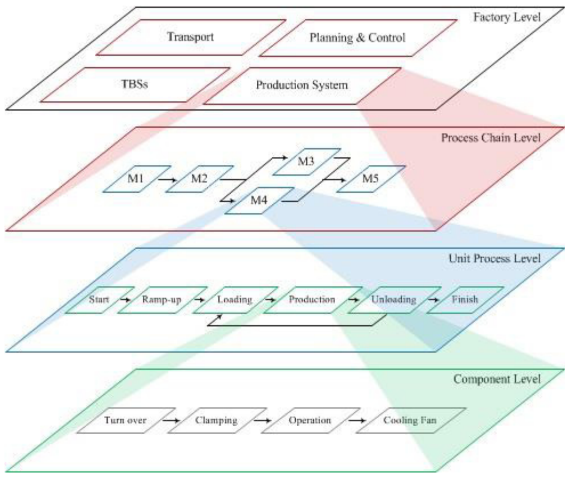

Figure 1 Hierarchical modelling framework [14]

3. Simulation model

A simulation model was developed in Anylogic®. Anylogic is a simulation program by XjTek using a subset of UML for Real Time (UML-RT) as a modeling language platform. The model of the whole factory is constructed following the bottom-up approach. Generic module of a single machine (unit process) is developed. The unit process module uses state-based modelling technique and considers different operational states. The component level is also embedded in this module. The process chain and the whole factory models are built upon the unit process module considering the configuration of production facilities.

3.1. Unit process and component level model

Basic unit process modules to represent machines are