Resource Utilization in Cloud Manufacturing – An Energy Perspective

Tao Peng, Shuiliang Fang, Renzhong Tang

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Tao Peng*, Shuiliang Fang, Renzhong Tang

Key Laboratory of Advanced Manufacturing Technology of Zhejiang Province
Department of Industrial Engineering, School of Mechanical Engineering, Zhejiang University
Hangzhou 310027, China
{tao_peng, me_fangsl, tangrz}@zju.edu.cn

Abstract. Living a "low-carbon" life has been widely recognized and is gradually adopted by the public. Such a trend becomes one of the main drivers for manufacturing innovations. Meanwhile, to meet the emerging requirements, such as providing highly customized product, building flexible and collaborative production, cloud manufacturing is proposed in recent years. A close examination of its environmental benefits is needed. In this paper, resource utilization is focused. In the architecture of cloud manufacturing, energy consumption is analyzed and re-evaluated systematically, including energy characteristics, added energy segments and required functions. Three key merits are identified, better resource integration and optimization, higher resource utility rate, and facilitated knowledge sharing mechanism. However, these improvements can be cancelled in an energy-unattended cloud manufacturing system, for example, ignorance of energy data or inadequate energy models. A framework is then designed for performing energy analysis in a cloud environment. Conclusions are given at the end.

Keywords: energy consumption; cloud manufacturing; resource utilization; framework

1 Introduction

Living a "low-carbon" life has been widely recognized and is gradually adopted by the public. People are demanding more of environmental-friendly products and processes. Such a trend becomes one of the main drivers for innovations in manufacturing. Meanwhile, intelligence for autonomous production, flexibility for highly customized products, and re-configurability for global collaboration are the representative features, imminently required by modern manufacturing [1]. This undergoing transformation is enabled by cutting-edge Information Technology (IT), such as cloud computing, and related smart technologies, such as Internet of Things (IoT) and manufacturing grid.

Cloud manufacturing, a world-widely featured manufacturing business model is proposed in recent years [2-4]. It mirrors the concept of cloud computing, and helps a

adfa, p. 1, 2011.

manufacturing company to align its product innovation with business strategy, build smart factory networks and respond efficiently to customers' needs. Besides that, less environmental impact is a major expectation. Although many research works on cloud manufacturing are being conducted [5-7], only a handful of them raise a concern on environmental aspect [8].

This paper studies resource utilization with a particular focus on energy consumption. The remainder of the paper is organized as follows. Section 2 elaborates the content of cloud manufacturing. A brief literature survey is presented. Overview of energy characteristics in cloud manufacturing, as well as pros and cons is then analyzed in Section 3. Following that, a framework of an energy analysis service systems is suggested in Section 4. Further discussions and conclusions are given at the end.

2 Cloud Manufacturing

Cloud manufacturing was born in the movement from production-centric to service-oriented manufacturing paradigm. Two types of cloud adoptions in the manufacturing sector are identified, manufacturing with direct adoption of cloud computing technologies and cloud manufacturing, the manufacturing version of cloud computing. The latter one is of interest in this study, which was defined as "*a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable manufacturing resources (e.g., manufacturing software tools, manufacturing equipment, and manufacturing capabilities) that can be rapidly provisioned and released with minimal management effort or service provider interaction*" [2]. It aims to provide an organization with the ability to visualize its resources, encapsulate and offer them as consumable cloud services, and manage them in a federated way.

2.1 Architecture and Deployment Modes

A upsurge of research interest in developing system architecture is observed. Adamson et al. [9] summarized existing architecture and frameworks of cloud manufacturing. Fig. 1 depicts the 4-layer cloud manufacturing architecture developed based on [2]. Various manufacturing resources, of both hard and soft types, collectively form a shared resource pool. They are then presented in a virtual resource repository, such as virtualized machine tools, service capability. Human resource represents both physical and intellectual ability. These virtualized resources are encapsulated as cloud services in the global service layer. In the application layer, general and user-specific applications can be developed, covering all three stages in product lifecycle, Beginning Of Lifecycle (BOL), Middle Of Lifecycle (MOL), and End Of Lifecycle (EOL). In cloud manufacturing, BOL spans from product design to finished product assembly. MOL mainly concerns the use stage of a product, also considers necessary maintenance and service. EOL covers product recycle, component reuse, part re-manufacture, and waste management and disposal. This allows complete product lifecycle management processes to be provided as consumable cloud services.

In developing such a 4-layer cloud manufacturing system, four options of deployment modes are available, public, private, community and hybrid. Public cloud realizes the key concept of sharing the services with the general public in a multi-tenant environment. Private cloud resides within one organization and/or its subsidiaries. Community cloud is shared between several organizations of a specific community. Hybrid cloud is a composition of two or more clouds that remain distinct entities but are also bound together, offering the benefits of multiple deployment modes [10]. Please refer to [2, 11] for more comprehensive information.

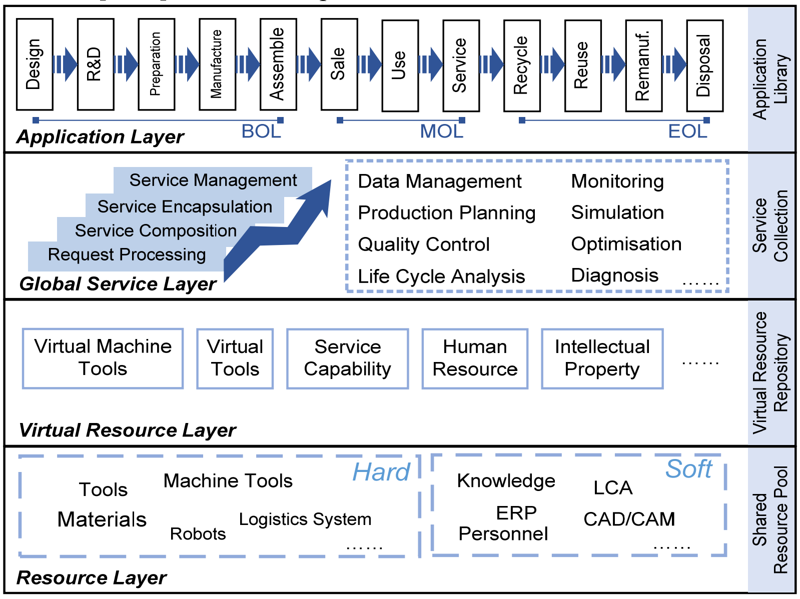

Fig. 1. Cloud manufacturing architecture

2.2 Business Benefits

A fully functional cloud manufacturing system is able to serve two key stakeholders: the enterprises that provide their resources/services, and the users that consume the available services for their own needs [10]. With the cloud approach, there is no need for every enterprise to make heavy capital investment in equipment purchase, factory maintenance, and specialized personnel. Instead, they could have instant access to the required resources, know-how or even complete solutions on a pay-as-you-go basis. Many benefits are anticipated, and three of them are highlighted here.

Resource re-organization. Current manufacturing business model can barely be considered as a private cloud, where manufacturing resource of an organization are loosely connected and partially shared within itself. In cloud manufacturing, manufacturing resources in a much wider spectrum, whether essential or redundant, can be offered in a resource pool and dynamically organized in line with the users' requirements in regardless of their ownership.

Flexibility. Characteristics such as ubiquitous network access or rapid scalability, offer an enterprise flexibility to manage its business. Moreover, with less investment in specific equipment, production can be quickly reconfigured with different service provisions, based on feedback from the dynamically changing market. Cloud manufacturing enables the shift from capital expenses to operating expenses.

Openness. New technologies emerge every day, which potentially upgrade existing ways of production. Though these cutting-edge technologies are critical to a company's competitiveness or even its survival, most Small and Medium-size Enterprises (SMEs) cannot benefit from them. In cloud manufacturing, these technologies and core-knowledge owned by an organization can be effectively shared as a consumable service, assuring its intellectual property well-protected.

Based on the aforementioned benefits, it is believed that cloud manufacturing would re-shape manufacturing industry and accelerate its reformation. To understand its "green" performance, resource utilization is studied in an energy perspective. Here, a public cloud is assumed.

3 Energy Analysis in Cloud Manufacturing

A conventional manufacturing company relies heavily on fossil fuel-based energy resource. Its environmental impact, therefore, must be paid attention to, until renewable/green energy resources are developed to a similar scale. Energy is hierarchically analyzed and estimated in existing manufacturing companies (Fig. 2). Among different departments at the enterprise level, e.g. design, management, logistics and etc., production is focused. Its subsidiary energy consumers can be further studied at the factory level, process level and machine level. In a cloud manufacturing enterprise, however, energy utilization in these four levels is being altered.

3.1 Energy Characteristics

The overall 4-level structure of energy analysis remains applicable, while energy characteristics at some levels are renewed. First of all, the organization of an enterprise has been extended. In cloud manufacturing, enterprises are virtually formed and managed based on the shared resources pool [11]. Normally, the resources involved in a particular service request belong to various cloud service providers. The centralized energy management system can be moved to the operating cloud platform. The tighter integration between the departments requires the inclusive of comprehensive energy data, such as energy cost by logistics, or one-off cost of material supply.

At the factory level, the overhead energy consumption, supporting lighting, Heating Ventilation and Air Conditioning (HVAC) and other infrastructure, is now scattered over multiple factories, therefore, energy is consumed on a pay-as-you-go basis. Moreover, due to increasing demand of highly customized products, rigid production lines and fixed processes are retiring, instead, processes need to be dynamically organized and agilely reconfigured so as to easily adapt to the "living" supply chain.

Dividing energy consumption into elementary and meaningful segments, e.g. state-based [13] and motion-based [14] approaches, provides a basic mechanism to study energy in cloud manufacturing. Less change happens at the machine level, but machine-related energy data need to be included in the virtualization process. For example, different ways of production organization result in large difference in energy consumption, simply by taking transportation, e.g. Automatic Guided Vehicles (AGVs) or conveyers, into consideration. Eventually, energy analysis can be performed by a self-organized, self-regulated cloud energy manager that functions based on data streaming from distributed resources. When an existing production line alters or a new production line to be built, it assists in process modeling and optimization.

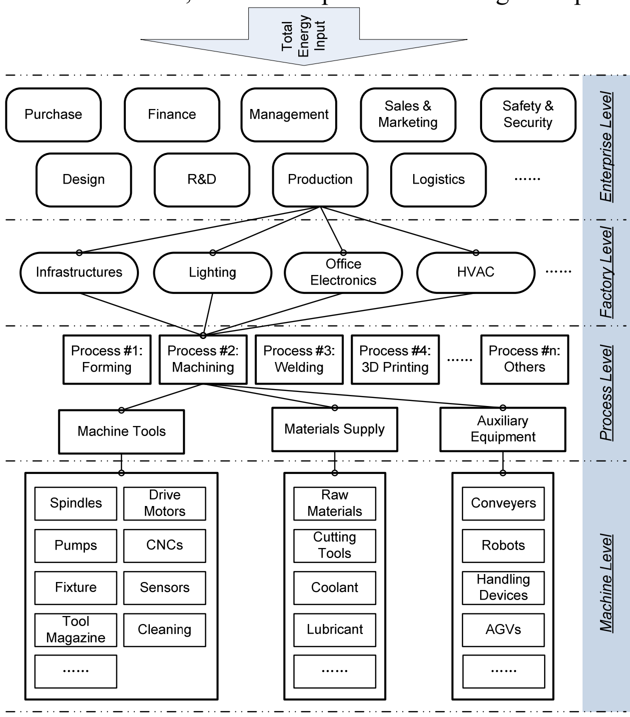

Fig. 2. Structure of energy analysis for production (modified from [12])

3.2 Pros and Cons

Energy study of cloud manufacturing reveals three key merits, that is better resource integration and optimization, higher resource utility rate, and facilitated knowledge sharing mechanism.

Resource integration and optimization. With a shared resource pool, cloud users are granted the access to more manufacturing resources and capabilities. This enables the optimum matching and best combination of manufacturing equipment in terms of energy usage, for instance, energy waste is minimized by excluding overqualified machines. Additionally, a better supply chain may be formed locally with several specialized SMEs to avoid unnecessary transportation within a large-size enterprise.

Resource utility rate. The meaning of higher resource utility rate is twofold. Firstly, companies can offer their unused or temporarily idle manufacturing equipment and/or packed with its associated personnel and know-how as cloud services. Secondly, the sharing mechanism allows more diversity of manufacturing tasks to be conducted on a machine, so that its full functions and capability can be utilized, and energy consumption data in different conditions can be obtained. SMEs that specialize in fewer manufacturing processes are more likely to develop the energy-efficient operating strategy for their resources.

Knowledge sharing mechanism. As a matter of fact, energy consumption behavior is often machine- and process- specific. Many models were developed using empirical or experimental methods. Yet, no single energy model can describe diverse manufacturing processes. The inherent sharing mechanism in cloud manufacturing is perhaps a solution. Cloud users who want to perform energy evaluation of a particular manufacturing process, can request relevant analysis services that utilize energy models maintained in a shared database. This saves modeling efforts and continuously improves accuracy and effectiveness of energy analysis.

Nevertheless, these improvements can be cancelled in an energy-unattended cloud manufacturing system, for example, ignorance of energy data or inadequate energy models. Such an issue may root in the fundamental objectives of developing a cloud manufacturing system. Cost is usually the main concern, which was evaluated in monetary form, in most cases. Energy as well as other environmental factors hardly carry weight in this sense. Large attention is paid merely to the high-cost resources. Though "green" requirements from the end-users are noticeable, they are not properly considered in the design stage and not reflected in the development stage [15].

Furthermore, there is an ongoing debate that whether the impact of improved energy efficiency on reducing energy use might be partially, or more than wholly, offset through “rebound” and “backfire” effects [16]. The economic factors underpinning rebound effects are straightforward: resource utilization improvements result in an effective cut in resource prices, which produces output, substitution, competitiveness and income effects that stimulate resource demands. However, the possible presence of strong rebound or even backfire does not mean that cloud manufacturing is inappropriate; rather it suggests that sharing alone are insufficient to generate environmental improvements. A coordinated system design is required.

4 EAS Framework

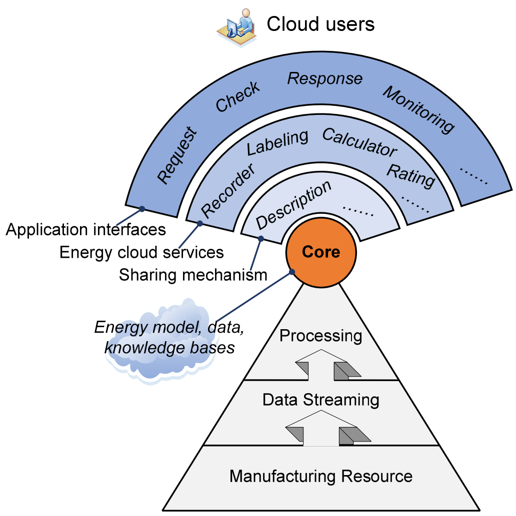

Fig. 3. Proposed EAS framework

A framework of an Energy Analysis Service (EAS) system is developed for cloud manufacturing. The basic principle in designing this framework is to consider energy utilization as an integral part and one of the main objectives for long-term competitiveness of an enterprise. Fig. 3 depicts the designed "tower" framework. The base of the tower is comprised of three levels, manufacturing resource, data streaming and processing. These are essential steps to reach the core level, energy model, data and knowledge bases. Based on the core, cloud users can utilize various publicized energy services via application interfaces, such as energy estimation and energy labeling.

Some key functions of energy-aware systems are also supported: (1) closed-loop data streaming (online energy monitoring, in-time feedback control), (2) energy calculation (componentized energy models, trustworthy simulation), (3) intelligent data processing (energy pattern analysis, energy supervisor and inspector, service rating), and (4) metering and billing system (pay-as-you-go style, energy traceability). Extra cost should occur at both cloud service provider's and user's ends, when user choose the less energy-efficient processes. This strategy evokes public "green" awareness and encourages continuous improvement of manufacturing processes.

The developed EAS system could be integrated with a cloud manufacturing platform (Fig. 4). Energy resource utilization is envisioned as a virtual application service, and intended to support online resource description, monitoring, and data analysis.

Fig. 4. Example of cloud manufacturing platform

5 Conclusions

Though the issue of energy consumption in manufacturing draws significant attention, manufacturers hold their further actions on adopting energy-related improvements, awaiting the proof of feasibility and benefits in production. Cloud manufacturing aims to reform the manufacturing industry, where companies can actively participate in a broader virtual enterprise, and cooperatively fabricate highly-customized product in a more cost-effective manner. Enabling technologies in the 4-layer cloud manufacturing architecture enhance resource integration and utilization, as well as meet the up-to-date requirements of global market.

New energy characteristics reveal the advantages introduced by cloud manufacturing, that is better resource integration and optimization, higher resource utility rate, and facilitated knowledge sharing mechanism. But these can be cancelled in an energy-unattended cloud system. The proposed EAS framework provides preliminary thoughts in developing energy-aware cloud services, which could be integrated with a functional cloud manufacturing platform. Some other critical issues exist in cloud manufacturing, such as physical equipment integration, logistics and transportation, data security and safety. Energy data should also be addressed in these processes.

It is time to change the dated view on overhead energy cost. Customer interaction in the product lifecycle imposes restrictions on energy utilization, which promotes "green" awareness, motivates the innovation in technology, and the introduction of greener products. System development and integration is planned as future works.

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