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Procedia CIRP 61 (2017) 347 – 352

www.elsevier.com/locate/procedia

The 24th CIRP Conference on Life Cycle Engineering

Operation Mode Study in Cloud Manufacturing Ecosystem

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Abstract

With cloud manufacturing and its shared big-data, the life-cycle management of the massive distributed manufacturing resources can be considered as an ecosystem, in which every entity makes their own decisions depend on the enriched information, which will affect the life cycle of the resources and the overall industry states. In this paper, an original operation mode with three extensions are proposed to describe the life cycle vicissitude of each resource. An agent-based model was designed to simulate the ecosystem modes from the very beginning, and the results show that the ecosystem has: 1) shorter job queue length and lower resource idle rate with incubation mode; 2) a little shorter job queue length and fewer amount of registered resource with outsourcing mode; 3) the fewest amount of registered resource but a little higher resource idle rate with metabolism mode.

Peer-review under responsibility of the scientific committee of the 24th CIRP Conference on Life Cycle Engineering

Keywords: Cloud manufacturing ecosystem; decision-making; operation mode; ecosystem evolution; agent-based simulation

1. Introduction

Manufacturing activities consume kinds of resources (e.g. material, equipment, manpower, nature resource), which will lead to substantial environmental issues. Arrangement of these resources to collaborate a manufacturing process is one of feasible approaches to reduce the idle rate of resources; the concept of cloud manufacturing [1, 2] provides an operating framework to realize the arrangement. However, the relationship among entities in a cloud manufacturing system become more complicated than that in current manufacturing systems, since the integration of advanced technologies makes it possible for individual to make decisions depend on enriched information. Entities' preferences stimulate the emergence of good resource arrangement pattern to support operation mode in the cloud manufacturing ecosystem. Hence, it's important to identify a suitable operation mode to meet most entities' preferences and to optimize the resources management.

In this paper, an original operation mode is designed to describe the basic decision-makings of entities in cloud manufacturing ecosystem, and then three extensions are proposed, namely metabolism mode, incubation mode and outsourcing mode. Finally, an experiment to validate these synthetic operation modes is designed, which uses an agent-based simulation method.

2. Review on cloud manufacturing and simulation

Resource consumption in manufacturing activities is inevitable, waste or idle of these resources are pervasive in current manufacturing systems [3]. Manufacturing innovation which driven by effective utilization is one key consideration of overcoming the environmental burden [4, 5].

This paper is scoped with the designs of mode to generate manufacturing service, which is an arrangement of resources on the cloud manufacturing platform, and to manage the overall manufacturing resources in high quality level at the meantime.

Platform operator can manage manufacturing service, which encapsulated distributed manufacturing resources intensively with appropriate business model [2]. Modular and multi-layer architecture are the most common approaches to build a cloud manufacturing platform or system framework [6, 7], Lv used the list of views to depict this multi-layer architecture [8]. Servitization is the key philosophy to operate

Peer-review under responsibility of the scientific committee of the 24th CIRP Conference on Life Cycle Engineering
doi:10.1016/j.procir.2016.11.154

cloud manufacturing [1]. A service can be created statically which comes along with a provider [6], or can be created dynamically according to task pattern, such method as 'Multi-Composition for Each Task' [9] that combines incompetent service as a whole. A service can also be created by AI planning-based automatic composition framework [10].

Simulation approach has been widely used in manufacturing systems on operations planning and scheduling, real-time control, operating policies, performance analysis [11]. In operating policies field, scheduling policies can be tested with simulation performance under given machine conditions [12], machine segmentation policies can be simulated in a combined MRP and Kanban production system [13]. Mourtzis et al. [14] explored a series of simulation-based solutions in industrial practices and concluded that research trends are in Internet- and cloud-based situations.

3. Cloud manufacturing ecosystem

Before introducing the cloud manufacturing ecosystem, we specify some basic definitions as following:

- Provider: the entity that provides resources;
- Resource: the basic task processing object with renewable capacity and unique type;
- Demander: the entity that publishes order that contains a set of tasks;
- Task: the basic object needs to be processed with resource-type cooperation;
- Task-part: virtual resource-type segmentation unit of one task as squares in Fig. 4;
- Service-call: the basic object that needs to be processed with both resource-type and resource-capacity cooperation;
- Service: the perform result of a service-call, a set of tasks;
- Platform: the place where individual interact with others;
- Resource-type cooperation: specific resources to process a job simultaneously;
- Resource-capacity cooperation: same type of resources to process a service-call simultaneously as in Fig. 3.

Platform is the cradle of the ecosystem and the incubator of manufacturing service; demander and provider make decisions through it to arrange the resources for task performance. Most recent researchers e.g. Wu et al. [15], described this operation procedure in cloud manufacturing as a tri-group user model that contains:1) users/customers, 2) application providers and 3) physical resource providers. Inspired by this model, we designed the original operation mode shown in Fig. 2 as the basis, interaction among entities is depicted by object flow (full lines) and information flow (dashed lines). A single order can be described by an activity-on-node (AON) network where the node represents the task and the arc represents the precedence relation of tasks. Each task should be performed with types of resources as listed in Tab. 1, and the processing of all the selected resources should start simultaneously. What each resource actually processes are the task-parts, and we denote the task-part which being processed as **active** part, the task-part that being selected (shadowed in Fig. 4) as **semi-active** part, the task-part which being assigned to the job queue as **inactive** part. Product, the performance result after the processing and assembly procedure, will be delivered to demander, then demander will change the rank value of the owner according to the review of the product.

3.1. Nomenclature and assumptions

Nomenclature

$\mathcal{T}_i$	Order that comes with demander, who can be inquired by $F(\cdot)$
t_{ij}	Task that belongs to $\mathcal{T}_i, t_{ij} \in \mathcal{T}_i$
p_{ij}	Process duration of t_{ij}
γ_{ij}	Expect quality of product as the process result of t_{ij}
r_i	Release time of all $t_{ij} \in \mathcal{T}_i$
f_{ij}	Actual finish time of t_{ij}
$\mathcal{P}_{ij}$	The set of predecessors of t_{ij}, determined by order and assignment procedure
mr_k	Resource that comes with provider, it can be inquired by $F(\cdot)$
δ_k	Quality of task-part processed via resource mr_k
$C_{k,\tau}$	Capacity of mr_k at time τ
$A_{k,\tau}$	Available capacity of mr_k at time τ
$\mathcal{L}_{k,\tau}$	The list of inactive job queue of mr_k at time τ with sequence
$\mathcal{H}_{k,\tau}$	The list of semi-active jobs of mr_k at time τ
$\mathcal{G}_{k,\tau}$	The set of active jobs of mr_k at time τ
$f_\theta^{(s)}$	Theoretical finish time of job_θ in $\mathcal{L}_{k,\tau_0}^{(s)}$ for schedule at τ_0
re_j	Remaining process time of t_j in $\mathcal{G}_{k,\tau_0}$ for schedule at τ_0
$\mathcal{A}_{ij}$	Subset of resource types required by t_{ij}
$q_{\alpha,ij}$	Required amount of resource in type α by t_{ij}, $\alpha \in \mathcal{A}_{ij}$
sc_l	Service-call which can be generated by provider
p_l	Process duration of sc_l
r_l	Release time of sc_l
$\mathcal{P}_l$	Predecessor set of sc_l
$\mathcal{A}_l$	Subset of resource types required by sc_l or provided by ms_l
ms_l	Service which is incubated after the finish of sc_l
Δ_l	Product quality which is produced via service ms_l
$q_{\alpha,l}$	Need resource capacity of ms_l in type $\alpha, \alpha \in \mathcal{A}_l$
$\mathcal{L}_{l,\tau}$	The list of job queue of ms_l at τ with sequence
$\mathcal{G}_{l,\tau}$	The set of active jobs of ms_l at τ
$\mathcal{R}_{ij,\tau}$	Resource candidate set of t_{ij} to select
$\mathcal{B}_{ij,\tau}$	Resource candidate type set of t_{ij}
$\mathcal{S}_{ij,\tau}$	Service candidate set of t_{ij} to select
$\mathcal{R}_{l,\tau}$	Resource candidate set of sc_l to select
$\mathcal{B}_{l,\tau}$	Resource candidate type set of sc_l
$R(\cdot)$	Rank inquire function about provider
$F(\cdot)$	Owner inquire function about resource or service
$P(\cdot)$	Type inquire function about resource type

Since demander and provider arrive successively, there is no upper bound for the subscripts (i, j, k, l, α). To scope our research, we make some assumptions as follows for the original mode.

- Operate of the ecosystem starts from the very beginning that no demander or provider was registered;
- Each single task should be assembled by its task-parts, and these parts should be processed simultaneously;
- The quality of product is determined by the worst quality of the selected resource;
- Resource are renewable that the available capacity will be return to when the process procedure finished;
- Provider can only schedule task-parts that in inactive status.

3.2. Master plan for original and extended modes

In original mode, ecosystem starts with void, then there comes the registration of provider and demander. A single **order** consists of a set $\mathcal{T}_i = \{t_{i1}, t_{i2}, \dots\}$ of tasks, which are interrelated by kinds of constraints. First, precedence constraints force **task** t_{ij} not to be started before all its immediate predecessors in $\mathcal{P}_{ij}$. Second, performing the tasks requires resources with limited capacities. Third, resources-type cooperation ensures all the task-parts should in active status. A single **resource** (mr_k) can only belongs to one type. While being processed, task t_{ij} requires $q_{\alpha,,ij}$ units capacity of the resources in type $\alpha \in \mathcal{A}_{ij}$ during every period of its non-