The 24th CIRP Conference on Life Cycle Engineering

Operation Mode Study in Cloud Manufacturing Ecosystem

Shengkai Chenb, Shuiliang Fanga,b,∗, Tao Pengb, Renzhong Tangb

aThe State Key Laboratory of Fluid Power Transmission and Control, College of Mechanical Engineering, Zhejiang University, Hangzhou, 310027, China

bKey Laboratory of Advanced Manufacturing Technology of Zhejiang Province, College of Mechanical Engineering, Zhejiang University, Hangzhou , 310027,

China

\* Corresponding author. Tel.: +86-135-8880-3980; *E-mail address:* me\_fangsl@zju.edu.cn

Abstract

With cloud manufacturing, platform operator is able to manage distributed massive manufacturing resources for manufacturing business. Ecosystem of cloud manufacturing has more complicated relationship among individuals than that in existing manufacturing system, every individual makes decisions depend on enriched information, which will help optimize for the overall industry. In this paper, an original operation mode with three extensions are proposed to describe the life cycle vicissitude of each resource. We designed an agent-based model to simulate the ecosystem from the very beginning, and the validation experiment result shows platform have: 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.

© 2017 The Authors. Published by Elsevier B.V.

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 resulting in substantial environmental issues. Properly arrange these resources to collaborate a manufacturing process is one of feasible approaches to reduce the waste during the consumption 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 existing manufacturing systems, since the integration of advanced technologies makes it possible for individual to make decisions depend on enriched information. In particular, Fig. 2 shows the basic procedures that need three main entities to make decisions on. **Demander** is the entity that publish manufacturing task, it prefers high quality of task performance; **Provider** is the entity that processes the task with the resources it provided prefer high use rate of resource; **Platform** it the intermediary entity that promotes the manufacturing activities, it prefers a suitable amount of registered resources to satisfy the needs of the market and an optimal life cycle management of resources. Entities’ preferences stimulate the emergence of good resource arrangement pattern that will lead to the emergence operation mode in the cloud manufacturing ecosystem. Hence, it’s important to identify a suitable operation mode to meet most of entities’ preferences and to optimize the resource management.

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

1. Review on cloud manufacturing and simulation
   1. Background

Resource consumption in manufacturing activities is inevitable, waste and idle of these resources are pervasive in existing manufacturing systems [3]. Effective utilization of resources and resource productivity driven manufacturing innovation is one key consideration to handle the environmental burden [4, 5].

In cloud manufacturing context, provider entity publishes manufacturing resources, demander entity publishes manufacturing tasks, platform arranges these resources properly to perform the tasks. In scope are the mode to generate manufacturing service, which is an arrangement of resources, and the mode to keep resource in high quality instead of low quality.

* 1. Literatures

Platform operator can manage manufacturing service that encapsulated distributed manufacturing resources intensively with appropriate business model [2], modular approaches and multi-layer architectures 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 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 operation 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.

1. Design of the ecosystem

Before introducing the design of the ecosystem, we specify some basic definitions first:

* Provider: the entity that provide resource;
* Resource: the basic task process object with renewable capacity and unique type;
* Demander: the entity that publishes order that contain bunch of tasks;
* Task: the basic object need 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 group of tasks;
* Platform: the place where individual interact with other and environment;
* Resource-type cooperation: resource in specific type to process a job simultaneously;
* Resource-capacity cooperation: part of resources in same type to process a service-call simultaneously as in Fig. 3.

Platform is the cradle of the ecosystem and the incubator for 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 design 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 represent the task and the arc the precedence relation of task. Each task needs to be performed with types of resources as listed in Tab. 1, and all the selected resource need to be start the processing simultaneously. What each resource actually processes is the task-part and we call the task-part is **active** when being processed, **semi-active** when selected resource is waiting as shadow in Fig. 4, **inactive** when this part is just assigned to the job queue. Product, the performance result after the processing and assembly procedure, will be delivered to demander, then demander change the rank value of the owner according to the review of the product.

* 1. Nomenclature and assumptions

**Nomenclature**

Order that comes with demander, who can be inquired by

Task belongs to

Process duration of

Expect quality of product as the process result of

Release time of all

Actual finish time of

The set of predecessor of , determined by order and some assign procedure

Resource that comes with provider, it can be inquired by

Quality of task-part processed via resource

Capacity of at time

Available capacity of at time

The list of inactive job queue of at time with sequence

The list of semi-active job of at time

The set of active job of at time

Theoretical finish time of in for schedule at

Remaining process time of in for schedule at

Subset of resource type required by

Required amount of resource with type by ,

Service-call generated by provider

Process duration of

Release time of

Predecessor set of

Subset of resource type required by or provided by

Service that incubated after the finish of

Product quality produced via service

Need resource capacity of with type

The list of job queue of at with sequence

The set of active job of at

Resource candidate set for to select

Resource candidate type set for

Service candidate set for to select

Resource candidate set for to select

Resource candidate type set for

Rank inquire function about provider

Owner inquire function about resource or service

Type inquire function about resource type

Since demander and provider arrives successively, there is no upper bound of the subscripts (). To scope our research, we make some assumptions as follows for the original mode, some of them will be modified in the extension modes.

* Operate of the ecosystem starts from the very beginning that no demander or provider is 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 in inactive status.
  1. 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 of tasks, which are interrelated by kinds of constraints. First, precedence constraints force **task** not to be started before all its immediate predecessors in . Second, performing the tasks requires resources with limited capacities. Third, resources-type cooperation requires all the task-parts in active status. A single **resource** () belongs to only one type. While being processed, task requires units capacity of the resources with each type during every period of its non-preemptable duration . Each resource has a limited capacity and available capacity at any point in time . This plan is much like the settings in RCPSP[16] except that the task here need to be processed with resource-type cooperation.



Fig. 1. Three Extended modes

The life cycle management of resource contains its vicissitude, which is the basis of the following extended modes in Fig. 1. Incubation and outsourcing mode are options for provider, while metabolism mode is an option for platform operator.

* 1. Original mode



Fig. 2. Original mode

A provider makes decision at time to respond to task if the belonging resource is type-matched with (). If , the provider will respond to the task need, demander of will add to and to . If is finally selected, available capacity of will change to . This available capacity will be restored after the processing of part.

A demander makes decision about resource selection from when . Without loss of generality, we suppose at time , the decision-making of demander can be formulated as the special case of general model, which aims at multi-objective function as Eq. 2.

If is selected by the demander of , then the provider will add part to if , , or to otherwise. If all the part of are in semi-active status, then these providers will change all the task-part status from semi-active to active and add to .

* 1. Incubation mode

Incubation mode describes the generating process of manufacturing service, the purpose of this mode is to remove the cooperation and assembly procedure among resources in advance by wrapping types of resources with certain quota up. A service is incubated as shown in incubation part of Fig. 1. As the example in Fig. 3, if task in Tab. 1 is finished, the first thing of incubation for the resource provider is to publish a job named **service-call** (), which is similar to task except for the capacity dominance feature, which means capacity of selected resource will be restored after the processing.



Fig. 3. Service incubation from in Tab. 1

The process result of one service-call is manufacturing **service** as shown in Fig. 3, which is actually a bunch of resources that come from selected providers in the system. There is no more cooperation and assembly procedure in service, and product quality will no longer be restricted to the worst quality of resources for the complementary effect. However service can only perform specified task. Now we can generalize task and service-call into **job**, resource and service into **machine** for the follow discuss.

1. Respond behavior

Provider of can respond to type-matched service-call (), as long as . If is finally selected, both available capacity and capacity will be changed as required, and these capacities will not be restored. Provider of will add to and to . When service is type-matched with (, ), provider of it will respond to as soon as possible, demander will add to .

2. Select behavior

Apart from the condition that , , provider of will select when , and the difference is that the (subset of decision variable ) here is also a set of selected resources in type . If the sum of capacity value in is less than the value required, this selection will not to be executed. Demander of will select when , and this implies that the resources candidates are not enough and there exists service candidates. This decision-making can be formulated as the special case of general model, which aims at multi-objective function as Eq. 5.

In more general condition where , demander of will select ether a bunch of resources or one single service.









*s.t.*









The decision variable is a vector that wraps up (). Eq. 1 is a multi-objective function that aims at high quality, high rank and low waiting queue length. Eq. 2 and Eq. 5 are the optimal decision in independent conditions. Eq. 3 determines the virtual rank value while Eq. 4 determines virtual queue length that are set in the worst cases. Eq. 8 is the decision to choose one of these two partial optimal decision. The determination of is tedious and insignificant so that we are not going to show the details.

3. Assign behavior

If is selected by provider of at time , the assign condition is more restrict, it should be changed into , we need to assign this type of job one by one. Assign to is very simple and there will be no semi-active status for , hence it will add to if , or to otherwise.

* 1. Outsourcing mode

Outsourcing mode can only be applied when incubation mode is applied, the meaning of this mode is to transfer task to idle resource. As outsourcing part shown in Fig. 1, this method reduces job queue length of one service to enhance the probability to be selected by new tasks. For each single task in , the only condition to make the outsource decision is that if the maximum delay () of task in both status decreases. Outsourcing mode makes it possible to paralleled process one job.

* 1. Metabolism mode

Metabolism mode controls the number of entity in the system by both restrict the arrival and eliminate the current entities. As metabolism part shown in Fig. 1, we can define machine scarcity as , this indicator will guide the metabolism module to execute, the object of metabolism is to improve overall resource quality without loss of manufacturing efficiency.

* 1. Provider schedule the jobs in machine

Table 1. Simple job configuration

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Job () | Entity class |  |  |  |  |  |
|  | Task | 0 | 5 | 7 | 0 | 7 |
|  | Task | 7 | 5 | 5 | 4 | 5 |
|  | Task | 6 | 0 | 5 | 2 | 3 |
|  | Task | 9 | 4 | 6 | 1 | 2 |
|  | Task | 1 | 0 | 3 | 2 | 3 |
|  | Service-call | 1 | 0 | 3 | 0 | 1 |
|  | Service-call | 0 | 5 | 7 | 7 | 1 |



Fig. 4. Simple instance schedule chart with 4 resources in 3 different types

Provider can schedule the inactive jobs on their machines to reduce the idle rate. All the job after service-call should be stay in inactive status until the service-call is finished. Therefore, provider can only makes decision on the schedule of tasks before the first service-call in when one of the active job in was finished at , we denote the set of schedule task at this time as .

Specifically, a simple instance with configuration Tab. 1 and schedule chart Fig. 4 will elucidate the settings. We here use the single uniform denotation  to distinguish these tasks and their related variables. In this instance, as shown in Fig. 4, horizontal dotted line constrained the available capacity of the resource for the subsequent jobs.

In every single resource, a schedule is given by a vector of ideal finish times wraps up (). Even though provider will not schedule the finish time of these job cannot be determined. The schedule model is:





 



*s.t.*

 

 

 

The schedule aim for each resource Eq. 9 is to minimum the maximum delay of jobs. Eq.11 ensures that all predecessors of each job finished before the job itself. Eq. 13 means that the finish time of activate job is determined. Eq. 14 ensures the capacity restriction at every time period and Eq. 15 defines the extreme situation of the finish time. Since Eq. 14 is a time dependent function, the schedule model cannot be solved with mixed integer programming (MIP) techniques.

1. Experiment and result Analysis

Because of the autonomous and self-directed features of individuals in the manufacturing ecosystem, we use ABMS technique [17, 18] to study such a complex system. Repast Simphony [19] package was utilized in this experiment.

* 1. Experiments

We design experiments to repeatedly simulate the operating of ecosystem with mode combinations in Tab. 3, which are the prototypes of feasible cloud manufacturing operating modes. Every single simulation goes with the main flow as show in Fig. 2. We use RanGen [20] to generate dataset in the well-known Patterson format as the continuously arriving order as the simulation input, related parameter settings are listed in Tab. 2. First 5 parameters are defined in [20], is the parameters of the arrival of user in simulation, is the initial capacity for .

Table 2. Order generating parameters setting

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | OS | CI |  | RF | RC |  |  |  |
| 10 | 0.3 | [2,3] | 12 | 0.3 | 0.5 | 0.2 | 0.3 | [20,30] |

We assume that providers and demanders are arriving as the Poisson process, in order to make sure the coming need resource capacity rate will not exceed the average coming resource capacity rate in average to prevent the task explosion, and we make sure that,



Table 3. Experiments mode grouping

|  |  |  |  |
| --- | --- | --- | --- |
|  |  | No metabolism | Metabolism |
| Resource-only |  | Mode 11 | Mode 12 |
| Incubation | No outsourcing | Mode 21 | Mode 22 |
| Outsourcing | Mode 31 | Mode 32 |

* 1. Result and analysis

Experiment in each group is simulated with same random seed to make no difference on the irrelevant configuration to our validation. After bunch of experiments with different random seeds, take random seed 776189616 as example, we run the simulation for 6000 tick time and the experiment’s results are displayed in Fig. 5 and Tab. 4, meaning of new most symbols are defined as the title of all the plots in Fig. 5, denotes the resource efficiency determined by Eq. 17, we find:



1) Most dotted lines are above the full lines with the same series in means that metabolism mode need lower number of provider and resource, with the price of higher number of queue length of the tasks in resources in the system to deal with the same amount of needs. Full lines are not much above dotted lines in means that task finish rate will be a little lower with the metabolism.



Fig. 5. Observed variable change with time

2) and both represent the job queue length, triangle and square line turned lower in means that incubation mode can help reduce the waiting of job, these two type of line above the circle line means the incubation mode do reduce the resource idle rate.

3) Triangle lines are a little above the square lines in means that outsourcing mode needs more resources to operate and can only reduce the job queue length a little.

4) There is no big difference among all the 6 modes in rank change. Provider in metabolism mode will get lower rank value for they cannot stay in the system for a longer time to get higher rank value. Provider in Mode 11 even will not promote their rank value, which means that the metabolism rate is very fast if without incubation mode.

Table 4. Average observed values

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Mode |  |  |  |  |  |  |
| Mode 11 | 1159.360 | 1644.201 | 1177.601 | 2053.727 | 8.388 | 0.801 |
| Mode 21 | *636.769* | *2031.215* | **692.716** | **1066.947** | 16.016 | 1.904 |
| Mode 31 | 779.413 | 1996.021 | *782.272* | *1203.748* | 15.174 | 1.658 |
| Mode 12 | 1439.831 | 1522.923 | 1797.883 | 2954.113 | 14.057 | 0.516 |
| Mode 22 | **343.444** | **2464.407** | 1316.952 | 1957.226 | *20.251* | 1.259 |
| Mode 32 | 1164.409 | 1907.011 | 1597.742 | 2428.155 | **20.652** | 0.785 |

5) Mode 22 is a very special mode that reached the balance within 6000 ticks, that the number of provider and resource changes little with time goes by. Because our experiment setting comply Eq. 16, the coming need capacity rate is lower than the coming capacity rate, Mode 12,22,32 will finally reach balance in the long run theoretically, but the appearance of service-call and metabolism mode itself is full of uncertainty, thus it’s hard to predict when other metabolism related mode will reach the balance

6) With the average data value shown in Tab. 4, metabolism with incubation but not with outsourcing mode is one ideal combine mode to maintain the system, resource will self-configured and controlled to justly meet the task need.

1. Conclusions, Limitations, and Future Research

The operation modes proposed in this paper represented ways to the arrangement of resource to handle the environmental burden, and the value showed in Tab. 4, reduced waste and idle of manufacturing resources have partially achieved.

As for extended modes we designed for cloud manufacturing ecosystem, incubation mode can realize a feasible solution for the formation of manufacturing service, shorten the job queue length and reduce the resource idle rate; outsourcing mode can cut down the amount of registered resource; metabolism mode can also cut down the amount of registered resource in price of a little higher resource idle rate. The combine of incubation and metabolism mode turns out to be a ideal maintenance pattern for operating.

However, we only proposed 3 extensions to combine and it may not fully describe the operation mode of cloud manufacturing system, it may also limit the evolution direction of the ecosystem. The assignment of service-call is oversimplified to prevent complex consequence, we will design new approaches to assign this job.

Acknowledgements

This work is supported by the National Natural Science Foundation of China (No. 71571161), the National High Technology Research and Development Program of China (863 Program) (No. 2015AA042101), and the Fund of Key Lab of AMT of Zhejiang Province (No. 2015QN01). The authors also gratefully acknowledge anonymous reviewers for their comments.

References

1. Li, B.H., Zhang, L., Wang, S.L., Tao, F., Cao, J., Jiang, X., et al. Cloud manufacturing: a new service-oriented networked manufacturing model. Computer integrated manufacturing systems 2010;16(1):1–7.
2. Xu, X.. From cloud computing to cloud manufacturing. Robotics and Computer-Integrated Manufacturing 2012;28(1):75 – 86.
3. Smith, L., Ball, P.. Steps towards sustainable manufacturing through modelling material, energy and waste flows. International Journal of Production Economics 2012;140(1):227–238.
4. Dornfeld, D.A.. Moving towards green and sustainable manufacturing. International Journal of Precision Engineering and Manufacturing-Green Technology 2014;1(1):63–66.
5. Li, W., Winter, M., Kara, S., Herrmann, C.. Eco-efficiency of manufacturing processes: A grinding case. CIRP Annals - Manufacturing Tech-nology 2012;61(1):59–62.
6. Tao, F., Zhang, L., Lu, K., Zhao, D.. Research on manufacturing grid resource service optimal-selection and composition framework. Enterprise Information Systems 2012;6(2):237–264.
7. Valilai, O.F., Houshmand, M.. A collaborative and integrated platform to support distributed manufacturing system using a service-oriented approach based on cloud computing paradigm. Robotics and Computer-Integrated Manufacturing 2013;29(1):110–127.
8. Lv, B.. A multi-view model study for the architecture of cloud manufacturing. In: Digital Manufacturing and Automation (ICDMA), 2012 Third International Conference on. July 31 2012-Aug. 2 2012, p. 93–97.
9. Liu, W., Liu, B., Sun, D., Li, Y., Ma, G.. Study on multi-task oriented services composition and optimisation with the ’multi-composition for each task’ pattern in cloud manufacturing systems. International Journal of Computer Integrated Manufacturing 2013;26(8):786–805.
10. Oh, S.C., Lee, D., Kumara, S.R.T.. Effective web service composition in diverse and large-scale service networks. IEEE Transactions on Services Computing Jan.-March 2008;1(1):15–32.
11. Smith, J.S.. Survey on the use of simulation for manufacturing system design and operation. Journal of Manufacturing Systems 2003;22(2):157 – 171.
12. Sabuncuoglu, I., Kizilisik, O.B.. Reactive scheduling in a dynamic and stochastic fms environment. International Journal of Production Research 2003;41(17):4211–4231.
13. Felberbauer, T., Altendorfer, K., Hübl, A.. Using a scalable simulation model to evaluate the performance of production system segmentation in a combined mrp and kanban system. In: Proceedings of the 2012 Winter Simulation Conference (WSC). 9-12 Dec. 2012, p. 1–12.
14. Mourtzis, D., Papakostas, N., Mavrikios, D., Makris, S., Alexopoulos, K.. The role of simulation in digital manufacturing: applications and outlook. International Journal of Computer Integrated Manufacturing 2015;28(1):3–24.
15. Wu, D., Greer, M.J., Rosen, D.W., Schaefer, D.. Cloud manufacturing: Strategic vision and state-of-the-art. Journal of Manufacturing Systems 2013;32(4):564–579.
16. Kolisch, R., Hartmann, S.. Heuristic algorithms for the resource-constrained project scheduling problem: Classification and computational analysis. In: Węglarz, J., editor. International Series in search & Management Science; vol. 14. Springer US; 1999, p. 147–178.
17. Macal, C.M., North, M.J.. Agent-based modeling and simulation. In: Winter Simulation Conference. Austin, Texas: Winter Simulation Conference; 2009, p. 86–98.
18. North, M.J., Macal, C.M.. Managing business complexity: discovering strategic solutions with agent-based modeling and simulation. Oxford University Press; 2007.
19. North, M.J., Collier, N.T., Ozik, J., Tatara, E.R., Macal, C.M., Bragen, M., et al. Complex adaptive systems modeling with repast simphony. Complex Adaptive Systems Modeling 2013;1(1):1–26.
20. Demeulemeester, E., Vanhoucke, M., Herroelen, W.. Rangen: Arandom network generator for activity-on-the-node networks. Journal of Scheduling 2003;6(1):17–38.