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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.

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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.

1. 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 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.

1. Cloud manufacturing ecosystem

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

* 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.

* 1. Nomenclature and assumptions

**Nomenclature**

Order that comes with demander, who can be inquired by

Task that 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 predecessors of , determined by order and assignment 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 jobs of at time

The set of active jobs of at time

Theoretical finish time of in for schedule at

Remaining process time of in for schedule at

Subset of resource types required by

Required amount of resource in type by ,

Service-call which can be generated by provider

Process duration of

Release time of

Predecessor set of

Subset of resource types required by or provided by

Service which is incubated after the finish of

Product quality which is produced via service

Need resource capacity of in type

The list of job queue of at with sequence

The set of active jobs of at

Resource candidate set of to select

Resource candidate type set of

Service candidate set of to select

Resource candidate set of to select

Resource candidate type set of

Rank inquire function about provider

Owner inquire function about resource or service

Type inquire function about resource type

Since demander and provider arrive successively, there is no upper bound for the subscripts (). 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.
  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 ensures all the task-parts should in active status. A single **resource** () can only belongs to one type. While being processed, task requires units capacity of the resources in 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 is 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, demander of will add to and to . If is finally selected, available capacity of will change as . 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 Eq. 1 -- 8, 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.

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.









*s.t.*









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 is one extension for the original mode as shown in Fig. 1, the meaning of this mode is to transfer task to idle resource, so that the overall manufacturing resource load can be balanced. This mode can only be applied when incubation mode is applied, because only service can handle all the task-parts in one task as a whole. In this mode, provider of can make decision to transfer task in any status by publishes the task to platform again, then its service’s job queue length can be reduced to enhance the service’s 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 also makes it possible to paralleled process one job.

* 1. Metabolism mode

Metabolism mode is one extension for the origin mode to controls the number of entity in the system, by both restrict the arrival and eliminate the current entities. This mode is a feedback mechanism, it needs the resource review and resource scarcity value to determine the platform is short of which resources.

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 to be the successively arrived 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 overcome the environmental burden, and the value showed in Tab. 4 shows that the idle of manufacturing resources are partially reduced, unit resource utilization in some mode are improved if they are compared with basic Mode 11.

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 an 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, which should be improved in our future works.

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