DYNAMIC SUPPLY-DEMAND MATCHING FOR MANUFACTURING RESOURCE SERVICES IN SERVICE-ORIENTED MANUFACTURING SYSTEMS: A HYPERNETWORK-BASED SOLUTION FRAMEWORK

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ABSTRACT

Nowadays, service-oriented manufacturing (SOM) systems (e.g., cloud manufacturing (CMfg), product service systems (PSS), etc.) have attracted more and more interesting and attention of researchers from many different fields. However, because of the complex and dynamic environment, one of the most important issues need to be addressed for the promotion and application of SOM system is the dynamic supply-demand matching and scheduling of manufacturing resource services. In this paper, the issue of supply-demand matching in the typical SOM system is carried out at first. Then the dynamics and different models facing different users and different demands are analyzed respectively. As a result, a hypernetwork-based solution framework of this issue and the cloud manufacturing platform adding with the related functions are proposed with consideration of multi-objects, statistical characteristics and evolution. Finally, some future works with big data and industrial Internet of things are pointed out in the summary.

Keywords: service-oriented manufacturing (SOM), cloud manufacturing, supply-demand matching, hypernetwork, dynamics, manufacturing resource services.

INTRODUCTION

As the new developing stage of advanced manufacturing systems (AMSs), service-oriented manufacturing (SOM) [1, 2] is a knowledge innovation and value creation (or value-added) system under the demand and drive of the integration of manufacturing and service. It devotes to realizing the maximal utilities of different users and the effective integration and sharing of various manufacturing resources and capabilities (MR&C) by enterprises collaboration based on some enterprise information systems (EISs). On the condition of the growing trend and demand of manufacturing servitization and socialization [3], SOM has attracted more and more attention of researchers in different fields. Moreover, in the typical SOM systems (e.g., cloud manufacturing (CMfg) [4, 5], manufacturing grid (MGrid) [6, 7], product service systems (PSS) [8], etc.), one of the key issues need to be addressed is the supply-demand matching and scheduling of manufacturing resource services [9].

However, it is dynamic changing constantly in the practical process of supply-demand matching and scheduling. Specifically, regarding to the dynamic “supply”, manufacturing resource services are published and released dynamically, the state and quality of services (QoS) as well as the correlations among services are evolving dynamically in the execution process. As to the dynamic “demand”, the appearance and accomplishment of manufacturing tasks are dynamic, the functional requirements and relationships of sub-tasks are also evolving dynamically. Therefore, how to reflect the aforementioned dynamic changes and achieve the supply-demand matching and optimal scheduling under the dynamic environment, is the key to determine the promotion and applications of SOM systems.

Refer to the analysis of the existing related researches, the importance and conditionality of supply-demand matching for manufacturing resource services has been recognized, and the related works have been carried out. There are many methods have been investigated to address the issue of supply-demand matching and scheduling, e.g., the methods based on template, artificial intelligence, agent, graph theory, platform[10], etc. However, these methods are mainly around the following three conditions: in a certain period, the issues of matching and scheduling (a) with the static manufacturing tasks and the static candidate resource services; (b) with the static tasks and the dynamic available services; and (c) with the static available services and the dynamic tasks. However, the related studies are still weak for the issue both with the dynamic tasks and the dynamic services. In addition, the above methods are just to carry out the corresponding solutions for one moment. In the coming era of big data, there is almost no relevant systematic study for the following problems, e.g., how to do the effective analysis based on the current
and historical data of matching, how to analyze the dynamic evolution and statistical characteristics, how to forecast future supply-demand matching issue and make optimal decisions, etc. That is to say, it lacks of the evolution analysis and dynamic statistical characteristics of supply-demand matching for manufacturing resource services.

Therefore, in order to address different important problems oriented to different users (i.e., service providers, consumers, and operator) in the application and operation of SOM systems, the models and theory of hypernetwork are introduced into the issue of manufacturing resource services supply-demand matching in SOM systems, then a hypernetwork-based solution framework of the dynamic supply-demand matching and the supplemented cloud manufacturing platform are provided.

**SUPPLY-DEMAND MATCHING IN SOM SYSTEM**

All manufacturing activities are to create value, while all manufacturing enterprises collaboration activities with value creation in SOM system are to achieve supply-demand matching for manufacturing resource services, as well as to make the collaborative manufacturing among enterprises base on the supply-demand matching. As a result, the issue refers to the following three items: supply, demand, and the matching.

As to supply in SOM system, it is the set of various social available MR&C involving in the whole lifecycle of product. These MR&C are distributed in different places, owned by different entities, and aggregated, searched and invoked as services on the Internet. In a brief statement, manufacturing resource services can be divided into the production-related services oriented to the processes and operations, and the product-related services oriented to the market and consumption.

As to demand in SOM system, it refers to the set of production-related and product-related manufacturing tasks in the whole lifecycle of product. These tasks need to be executed and completed by invoking different services, e.g., a single service for the simple task, and the composited services for the complex or compound tasks. In the public applications of SOM systems, the simple tasks and complex tasks exist concurrently.

Finally to the matching of supply and demand in SOM system, it is a relatively generalized concept. It carries out the mapping relations between services (supply) and tasks (demand) which contains both two aspects of resource allocation and demand allocation. Then the results of which service to execute which task are worked out. Besides the quantitative matching between supply and demand, the mapping

<table>
<thead>
<tr>
<th>Demand types (In a certain period of time)</th>
<th>Mapping types</th>
<th>Timing constraints</th>
<th>Implementation process of supply-demand matching</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individually task</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A simple task</td>
<td>One service for one task</td>
<td>Without</td>
<td>√</td>
</tr>
<tr>
<td>A complex task</td>
<td>Multiple services for one task</td>
<td>One service for one subtask; One service for multiple subtasks</td>
<td>With</td>
</tr>
<tr>
<td>Multiple simple tasks</td>
<td>One service for one task; One service for multiple tasks</td>
<td>With</td>
<td>√</td>
</tr>
<tr>
<td>Multiple complex tasks</td>
<td>Multiple services for one task; Multiple services for multiple tasks</td>
<td>One service for one subtask; One service for multiple subtasks</td>
<td>With</td>
</tr>
<tr>
<td>Multiple tasks</td>
<td>One service for one task; One service for multiple tasks; Multiple services for one task; Multiple services for multiple tasks</td>
<td>One service for one task/subtask; One service for multiple tasks/subtasks</td>
<td>With</td>
</tr>
</tbody>
</table>
relations still reflect the optimal selection, composition, scheduling and operations based on the functional matching between supply and demand. What is more, the continuity of task execution determines the continuity of supply-demand matching, and also resolves the double decisions of static pre-scheduling and dynamic re-scheduling.

DIFFERENT ISSUES OF SUPPLY-DEMAND MATCHING IN SOM SYSTEM

The supply-demand matching in SOM system is a complex issue. For the generalized concept of supply-demand matching, it is consisted of the following six kinds. For instance, the quantitative matching and object matching of supply and demand; the matching of supply and demand for a single product or service, and for the multiple products or services; the enterprise-made matching of supply and demand under the decentralized decision making, and the system-made matching of supply and demand under the centralized decision making.

Moreover, oriented to different users and different demands, it would be paid attention to different requirements. No matter to the simple or complex tasks and the single or multiple tasks, the characteristics of the corresponding supply-demand matching issues are summarized as shown in Table 1.

DYNAMICS OF SUPPLY-DEMAND MATCHING IN SOM SYSTEM

The other characteristic of complexity of the supply-demand matching is the dynamics in SOM system. The SOM system and its supply-demand matching for resource services are dynamic complex systems. The dynamics are revealed in the following four aspects.

A. Complexity and dynamics of manufacturing tasks demand

Different from service-oriented computing, manufacturing tasks demands in SOM system are not only the demands of processor, bandwidth and memory, but also the comprehensive demands of various heterogeneous MR&C. Meanwhile, manufacturing tasks demands are dynamic, randomized, concurrent and large-scale because of the dynamic evolution of emerging, exiting, quitting, functional demand, process demand, relationships among subtasks, etc. In addition, there also are characteristics of variety, broader applications, execution continuity, and orientation to the whole lifecycle of product.

B. Heterogeneity, dynamics and complexity of manufacturing resource services

SOM is with the compliance of architecture and self-organizing management model of service-oriented architecture (SOA). The quantity and variety of resource services in SOM system are growing continually, the emergency, releasing, performance, status, QoS are ever changing. Moreover, the collaborative behaviors and correlation among different services are diversiform, e.g., similarity, competition, cooperation, etc. Each service belongs to different enterprises, and is used under different interest and objectives. Therefore, such many resource services in SOM system form a dynamic and complex network. For the requirements of supply-demand matching and scheduling of resource services, it is necessary to adjust and evolve this network to respond the changing of internal strategy and external environment.

C. Complexity and dynamics of supply-demand matching process

In the supply-demand matching process, except the dynamics of resource services and tasks, the consideration of pre-scheduling, real-time scheduling, fault-tolerance, re-scheduling and other issues facing different demands and tasks cannot be ignored. It also needs to meet the different or even conflicting objectives of different enterprises. As a result, to address the supply-demand matching is a quite complex issue, and it must adapt to the dynamic changing environment.

D. Dynamics of enterprises cooperation partnership

Obviously, orient to the respective objective maximization of different enterprises, the collaboration relationships of enterprises depending on the supply-demand matching for resource services are also not constant. How to do the statistical analysis based on the current and historical matching data which optimizing the cooperation mode and relationships among numerous enterprises, is a multiple-objective and multiple-constrains dynamic challenge.

On the basis of above analysis, the dynamics have such important influence on SOM system and the supply-demand matching in it. It is worth mentioning that, the uncertainties of user participation in the dynamic environment is also reminded. Regarding whether supply or demand is uncertain or dynamic, the issues of supply-demand matching to be addressed can be divided into 16 kinds of models, as summarized in Table 2. According to the difference in initial state, there are 4 models of the matching with certain supply and certain demand, the matching with certain supply and uncertain demand, the matching with uncertain supply and certain demand, and the matching with uncertain supply and uncertain demand. On the other hand, in accordance with the difference in implementation process, there also are 4 models of the matching with static supply and static demand, the matching with static supply and dynamic demand, the matching with dynamic supply and static demand, and the
The hypernetwork [10, 11], or called the network of networks, is a special kind of complex networks. Compared to complex networks, hypernetwork can provide much better description on the interaction and influence between networks. In addition, with the characteristics of multi-layers, multi-attributes and multi-standards, it is a new idea to achieve the supply-demand matching issue in dynamic SOM system with models and theory of hypernetwork. The characteristics of hypernetwork reflected in the supply-demand matching issue in SOM system are summarized in Table 3.

Table 3 The applicability analysis of hypernetwork applied into the supply-demand matching issue in SOM

<table>
<thead>
<tr>
<th>Characteristics of hypernetwork</th>
<th>Characteristics reflected in the supply-demand matching issue in SOM system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network of networks</td>
<td>The contractible graph of the subsection of service/task, function-similar service sub-network</td>
</tr>
<tr>
<td>Multi-layers</td>
<td>The service layer, the task layer, the user layer</td>
</tr>
<tr>
<td>Multi-classes</td>
<td>The class of service/task, the class of enterprises/users, the class of system</td>
</tr>
<tr>
<td>Multi-attributes/ Multi-standards</td>
<td>Multi-attributes comprehensive utility</td>
</tr>
<tr>
<td>Conflicting optimization</td>
<td>Decentralized decision making (provider-centered, consumer-centered), and centralized decision making (system-centred) [12, 13]</td>
</tr>
<tr>
<td>Interaction of networks</td>
<td>Heuristics of service/task network for the generation of new matching relations an matching optimization</td>
</tr>
</tbody>
</table>

Therefore, a hypernetwork-based solution framework of dynamic supply-demand matching is proposed. As shown in Figure 1, the key technologies referred to this framework mainly include the modeling of supply-demand matching hypernetwork (Matching-Net), comprehensive evaluation, hypernetwork-based models and algorithm implementation of supply-demand matching and dynamic scheduling, hypernetwork-based statistical analysis and evaluation of supply-demand matching and enterprise collaboration, etc. Because the last three parts are very complex due to the specific different supply-demand matching issues, it would be devoted to achieve the supply-demand matching and scheduling oriented to different demands and different dynamics in our further works. In this section, there just is the elaboration of Matching-Net.

Taking both manufacturing resource services and tasks into account, the Matching-Net is consisted of manufacturing service network (S-Net), manufacturing task network (T-Net), and the hyperedges between S-Net and T-Net. Obviously, there are two kinds of nodes and three kinds of edges in the model of Matching-Net. The two kinds of nodes are:

- The service nodes abstracted from various MR&C,
- The task nodes in the real-time operation of SOM system.

While, the three kinds of edges are as follows:

- The edges among service nodes in S-Net,
- The edges among task nodes in T-Net,
- The hyperedges between service nodes in S-Net and task nodes in T-Net.

In addition, in order to analyze and evaluate the supply-demand matching and scheduling in enterprise layer, it is better to model the Matching-Net with consideration of the subjection of services/tasks and enterprises/users. The specific implication of each node and each edge in Matching-Net is summarized in Table 4.

Table 4 The different relations of different nodes in supply-demand matching hypernetwork

<table>
<thead>
<tr>
<th>Service nodes, S</th>
<th>Task nodes, T</th>
<th>Enterprises nodes, E</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-S: function-similar relation (competitive, alternative), function-complementary (composable), etc., among services</td>
<td>T-T: demand-similar or demand complementary, progress constraint, etc., among tasks</td>
<td>E-E: cooperative, competitive relation, other business connection among enterprises</td>
</tr>
<tr>
<td>S-T: which service to execute which task</td>
<td>S-E: which service is affiliated to which enterprise</td>
<td>T-E: which task is affiliated to which enterprise</td>
</tr>
</tbody>
</table>

Moreover, the dynamic evolution of Matching-Net is also used to simulate the dynamic environment of SOM system effectively. Known from the summary in Table 5, the evolution operations of each node and edge in Matching-Net indicate the dynamic operation of SOM system and the supply-demand matching and dynamic scheduling demand in it.

Table 5 Summary on the dynamic evolution operations in the supply-demand matching hypernetwork

<table>
<thead>
<tr>
<th>Evolutions</th>
<th>The detailed dynamic evolution operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-Net</td>
<td>A new service node is added;</td>
</tr>
<tr>
<td></td>
<td>A new services chain is added;</td>
</tr>
<tr>
<td></td>
<td>A service is deleted;</td>
</tr>
<tr>
<td></td>
<td>A services chain is deleted;</td>
</tr>
<tr>
<td></td>
<td>A new edge is generated;</td>
</tr>
</tbody>
</table>
CLOUD MANUFACTURING PLATFORM ADDING THE FUNCTIONS OF HYPERNETWORK-BASED SUPPLY-DEMAND MATCHING

On the basis of the existing service platform of cloud manufacturing or cloud-based manufacturing platform [14-16], it is necessary to develop and supplement the corresponding functions for the hypernetwork-based supply-demand matching. These function modules actually support the dynamic changes of status, quality and function of services, as well as the dynamic changes of status, function and process of tasks. They are also used to achieve the supply-demand matching, the evolution analysis of S-Net, T-Net and Matching-Net in the dynamic environment. The sub-systems and corresponding functions are mainly three parts as follows. Figure 2 describes the important function modules and workflow of cloud manufacturing platform after adding the hypernetwork-based supply-demand matching related functions.

SUMMARY AND FUTURE WORKS

Regarding to the development of manufacturing servitization, manufacturing socialization, and demand personalization [3, 17], the promotion and applications of SOM systems are the inevitable tendency. However, under the dynamic operation and application environment of SOM systems, the high real-time supply-demand matching for manufacturing resource services is one of the most important challenges and problems need to be addressed. Especially, oriented to numerous conditions of different demand, different dynamics and different uncertainties, the issues of supply-demand matching and dynamic scheduling are extremely complex. There are so many differences between each kind of issue that the unified method is unable to solve these important problems. The models and theory of hypernetwork make the solution of these problems possible.

Besides the aforementioned that supply and demand matching and scheduling issues specific to the different demand and dynamic environment need to be paid a lot of attention and works on them,
there still are the following works to be undertaken and to be improved with the development of information technologies and the degree of enterprise informatization.

*The mutual mapping and influence of supply-demand matching, enterprise collaboration and value creation.* Due to the social and decentralized characteristics of supply and demand of resource services, the result of mapping and matching is the actual enterprises collaborative network (ECN) or value creation network. Therefore,

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**Figure 2** The flow chart of improved cloud manufacturing platform for the hypernetwork-based supply-demand matching
how to analyze the collaboration model based on the matching results, how to reasonably evaluate and improve the supply-demand matching as well as value creation using the analysis results, thereby improving the statistical data analysis and mining of SOM systems, are the follow-up research focuses.

The applications of big data in SOM system and its supply-demand matching for resource services: evolution, statistics, mining and forecasting. With the dynamically generated and updated of matching relationships in the operation of SOM system, there are such many data about the aggregation of services, the emergence of manufacturing tasks, and the collaborative modularity of enterprises. How to get the desired statistical analysis based on the historical matching data for the system and different users (e.g., the rate of resource utilization and sharing, the rate of task execution, etc.), how to conduct the mining of related laws and characteristics, and to work out demand forecasting and push-type management of SOM system, are interesting issues need to be valued and resolved with the advent of big data era.

The integration and perfection of SOM systems (or cloud-based platform) and industrial Internet of things (IoT) [18]. With the continuous application of SOM system, users’ functional requirements of service platform are getting higher. For the dynamic intelligent matching of resource services in the actual application process, the dynamic matching, dynamic evolution, statistical analysis, collaboration evaluation and other function modules are needed to be specifically improved and implemented. In addition to the lateral expansion of functions, the vertical integration and fusion of the existing cloud service platform, EISs, industrial IoT with the improved system is even necessary, so as to promote the full realization of big data in manufacturing.

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