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Cloud-enabled sharing in logistics product service system

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Abstract

Manufacturing enterprises are attempting to change from product suppliers into product-service providers through product-service integration during product lifecycle. In this context, logistics capability plays a significant role in transformation and upgrading, apart from design and manufacturing capability. To further improve logistics capability, logistics product service system (LPSS) is proposed based on product service system. This paper focuses on provision of idle logistics resource sharing for promoting LPSS. In order to share idle logistics resources, a model for logistics product service allocation is established firstly. After that, a Vickrey-Clarke-Groves-based payment rule is designed to complete transaction. Finally, a demonstrative case with the logistics product service provider and eight manufacturers is presented to illustrate the feasibility and applicability of the proposed method.

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Keywords: Product-service system; Cloud manufacturing; Vickrey-Clarke-Groves (VCG) mechanism; Logistics product service allocation

1. Introduction

With the development of advanced manufacturing modes, such as cloud manufacturing [1], manufacturing grid [2] and global manufacturing [3], manufacturing enterprises attempt to change from product manufacturers into product-service providers through product-service integration during product lifecycle. This transformation will increase the complexity in manufacturing industry, since they have to confront of increasing market fluctuation, shortened product lifecycle and demand for highly customized products. Thus, it is crucial to respond to market rapidly. Apart from design and manufacturing capability, logistics capability also plays a significant role in fulfilling customer orders.

Logistics concerns the management of the movement and storage of materials, and the corresponding information, which takes place between suppliers, manufacturers and customers [4]. Generally, logistics activities occupy nearly 95% execution time of the production process, which impact on the whole production efficiency [5]. Hence, only when logistics is able to provide production systems with the right required input factors at the right time in the right quality from the right source to the right place can Industry 4.0 come true in its pure vision [6]. In the context of Industry 4.0, logistics can be reshaped by Physical Internet so as for improvements in logistics efficiency and sustainability, and industry-related items (such as material, sensors, machines, products and containers) are all connected and communicate with each other through cyber-physical system (CPS) and Internet of things (IoT) [7]. For instance, CPS-based smart control model for shopfloor material handling is designed, which makes it possible that Automated Guided Vehicles have capability of active sensing, interaction with each other and self-decision [8].

Product service system (PSS) is a system where product and its associated services are combined together in a certain proportion and provided to customers in a reasonable way, by selling or renting or even mixing [9]. In recent years, PSS has been regarded as one of the most effective way for moving society towards a resource-efficient circular economy [10]. In order to realize circular economy, theoretical guidance for developing sustainable product-service offerings in the early

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planning phase is discussed to make it possible that companies co-create sustainable value with their stakeholders. Besides, customization-oriented PSS methodology is studied as an important part of PSS. For example, a system-based conceptual framework for PSS engineering is proposed to better support product-service integration in PSS [11]. And an integrated product service system modelling methodology is presented for developing a systematic and complete PSS strategy, and it is tested by a case study of clothing industry [12]. Moreover, a Meta-model for PSS is developed based on system engineering [13]. This model can support the integration of the final framework for the formalization of PSS through life knowledge. Due to advantages of PSS, researchers gradually extend the concept of PSS to logistics product service system (LPSS).

Recently, LPSS has been drawn much interest. LPSS is defined as a systematic package in which intangible logistics resources are combined with associated logistics services as well as attachments to complete various logistics activities. Many pilot studies have been investigated. For example, Supply Hub in Industrial Park (SHIP) is an extension of the concept of supply hub and is a public warehouse providing warehousing and logistics services for manufacturing enterprises located within an industrial park [14]. And the problem where SHIP and manufacturers interact to optimize their decisions on storage pricing, replenishment, and delivery is solved by a bi-level programming method [15]. An interactive decision making problem between a SHIP and its member enterprises in transportation service sharing is also discussed and solved [16]. To support the above decision making, IoT-enabled SHIP is developed based on physical asset service system [17]. Service capability maturity model based on analytical target cascading method is proposed for public warehouse product service system to configure resource and calculate capability maturity, and a case is studied to verify the feasibility and applicability of the proposed model [18]. Furthermore, smart box for cloud logistics is also designed and applied to deal with challenges that are composed by a lack of sharing, standard, cost-effective and environmental package, and efficient optimization method for logistics tasks distribution [19].

However, most of research mainly focuses on allocating the services provided by logistics product service provider, but ignores allocation of these idle resources owned by individual manufacturer. With the population of the concept of sharing economy, allocation of idle resources should be an important part of intangible services in LPSS, which can effectively promote LPSS. Although a framework for allocating idle logistics resources is proposed based on cloud manufacturing [20], there is still lack of an effective method. Therefore, this paper majorly continues to further deepen and exploit the potential advantages of product service system in logistics product service allocation based on cloud manufacturing (CM). CM is regarded as a new type of product service system to allow manufacturers to create new revenue streams and bring down costs [21]. Auction is an effective way to determine the price by the supply and demand, and can be implemented in distributed systems such as CM system. Hence, in this paper, we investigate a Vickrey-Clarke-Groves (VCG) mechanism [22–24] for logistics product service allocation. This mechanism is applied in transportation service procurement [25,26] and B2B e-commerce logistics [27], etc. The following case is considered. The logistics product service provider company provides a cloud platform for its member manufacturers to share idle logistics resources and acts as an auctioneer to operate an auction. Manufacturers who own surplus logistics resources can trade them with others who lack of relevant logistics resources via CM system.

The rest of paper is organized as follows. The problem is described in section 2. In section 3, we formulate VCG-based logistics service allocation model, give its properties and present a demonstrative example to show how the model works. In section 4, our work is summarized and future work is presented.

2. Problem description

Consider a system with a logistics product service provider company and a group of manufacturers. These manufacturers are its customers or potential customers. The logistics services provider company designs a logistics product service system that encompasses tangible physical services (e.g. trucks, forklift and human resources, etc.) and intangible services (e.g. information service and decision service, etc.). A kind of intangible services studied in this paper is that the logistics product service provider company provides a platform allowing some customers (suppliers) to share their own private idle logistics resources and other customers (users) to employ these resources at low cost, as shown in Fig, 1.

Fig. 1. The concept of sharing logistics product service.

This service can benefit the stakeholders. For customers or potential customers, who are suppliers, they can create new revenue streams and bring down costs by sharing their idle logistics resources; for those who are users, they can enjoy logistics service resource at low cost, because there is price competition between the logistics product service provider company and suppliers; for the logistics product service provider company, this service can popularize the whole logistics product service system, because potential customers are willing to participate in this system to reap benefits and may attempt to use other services provided by this system in the long run.

However, a key challenge faced by the logistics product service provider company is how to allocate the idle logistics resources in an appropriate way. More specifically, users are more willing to employ the idle logistics resources at the lowest cost. On the contrary, suppliers would like to make as much profit as possible with these idle logistics, which results in objective conflict. Hence, how to organize trading market and make it trading successfully should be solved by design payment rules. Besides, when a user would like to require a large number of logistics resources and each supplier can only satisfy a part of the user's resource requirements, which of users can be winners should be selected. Overall, all of stakeholders in logistics product service system are sensitive to the price when allocating and trading the idle resources.

In this paper, we propose an effective auction method to realize logistics resource sharing. This logistics resources are virtualized and encapsulated as logistics product services. Eventually, sharing idle logistics resources can be defined as a logistics product service allocation problem. The following problem is solved. We define that one unit item refers to one indivisible physical entity, for example, a truck, a smart box or a forklift; a bid denotes a supplier's declaration which includes the quantity and one bidding price. Notice that given bids, this method can trade any type of logistics product service. Thus, we ignore what kind of logistics product service is going to be allocated and only focus on the quantity and price of logistics resources.

As shown in Fig. 2, a user would like to demand D^t unit items in period $t(t \in T)$, and minimize logistics cost. And supplier $j(j \in J)$ would like to provide P_j^t unit items in period t. Both D^t and P_j^t are common knowledge. Let b denote the valuation of a user, s_j and $\hat{s}_j$ the valuation and the bid price of supplier j for supplying P_j^t units items. All the suppliers submit their own atomic bids. This means that suppliers sell all of their units if they finally trade successfully or none of their units if they fail to trade finally. We assume that the logistics product service provider company is one of suppliers participating in trading. Considering this assumption, we assume that the number of logistics service resources is sufficient enough if any one of the suppliers is removed. The logistics product service provider company also acts as an auctioneer.

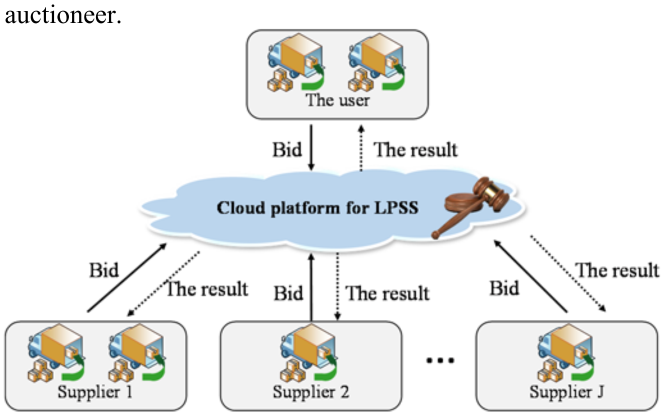

Fig. 2. The trading market.

3. VCG-based logistics service allocation model

3.1. Model

Given the abovementioned problem description, the total logistics product logistics cost can be minimized by formulating the following integer programming problem (IP):

$$\min \sum_{j=1}^{J} \hat{s}_j \cdot \eta_j \tag{1}$$

$$\text{s.t.} \sum_{j=1}^{J} P_j^t \cdot \eta_j \geq D^t,\ t \in T \tag{2}$$

$$P_j^t \geq 0,\ \forall t, j \tag{3}$$

$$\eta_j \in \{0,1\},\ j \in J \tag{4}$$

where $\eta_j \in \{0,1\}$ implies whether or not supplier j is selected to trade. The objective function (1) is to minimize the total logistics cost of a user. Constraint (2) guarantees that supply capacity is more than demand capacity. Constraint (3) ensures that supplier j provides P_j^t unit items and does not demand P_j^t unit items. Based on this model, the winners are determined.

3.2. O-VCG Mechanism

We introduce the O-VCG auction mechanism to solve the above problem. Let $V(J)$ be the value of (IP), and $V(J \setminus j)$ be the value of (IP) if supplier j is removed from the auction. Ties are broken arbitrarily. Recall that in our auction, the logistics product service provider acts as an auctioneer and suppliers as bidders.

Our auction proceeds as follows:

Step 1: A user submits the demand quantity (X^t unit items) and the reservation value b for X^t unit items to the logistics product service provider (auctioneer);

Step 2: Each supplier $j \in J$ submits the bid $(\hat{s}_j, P_j^t)$ to auctioneer;

Step 3: Auctioneer determines the set of winner J^* by solving the (IP). P_j^t unit items from supplier $j \in J^*$ are assigned to the user, where $\{P_j^t\}_{j \in J^*}$ is an efficient allocation achieving $V(J)$.

Step 4: Each supplier $j \in J^*$ will be paid by the user by a VCG payment of $p_j = \hat{s}_j - (V(J) - V(J \setminus j))$, and the utility of supplier $j \in J^*$ is $u_j = V(J \setminus j) - V(J)$ if suppliers' bids are truthful. Then, the total logistics product service cost of the user can be calculated by the function $C = \sum_{j=1}^{J^*} p_j = \sum_{j=1}^{J^*} (\hat{s}_j - (V(J) - V(J \setminus j)))$. If $b > C$, then the trade succeed; otherwise, then the trade fails.

Theorem 1. The O-VCG auction mechanism is an efficient, incentive compatible, individually rational mechanism that ensures balances the budget.

Theorem 1 indicates the O-VCG auction mechanism can maximize the total social welfare, which means the allocation solution can maximize the sum of participants' utility; induce all the stakeholders, who participate in the auction, to submit their bids truthfully, which means bidding price $\hat{s}_j$ of supplier j is equal to reservation price s_j; ensure participants' non-negative utilities, which can encourage them to participate in the auction; and logistics product service provider does not run the auction at a loss.

3.3. A demonstrative case

This section will illustrate a demonstrative case to help understand logistics product service allocation procedure in LPSS environment (see Table 1). A cloud platform with one user and eight suppliers has been chosen in this case. Assume that a user want to purchase 37 unit items in period t for RMB 275. And eight suppliers' bid information is given in Table 1. In this example, winners of eight suppliers selling successfully are determined firstly according to the model proposed in section 3.1. They are supplier 1, supplier 2, supplier 3, supplier 4 and supplier 7. And $V(J)$ is obtained and is equal to 213.07. Then, by $p_j = \hat{s}_j - (V(J) - V(J \setminus j))$, payment of each supplier can be calculated: $p_1 = 67.15$, $p_2 = 33.00$, $p_3 = 33.00$, $p_4 = 67.15$ and $p_7 = 67.15$. Finally, based on the payment of suppliers, the total logistics product service cost of the user is $C = \sum_{j=1}^{J^*} p_j = 267.45$. Since $C < 275$, the trade succeed. Based on $u_j = V(J \setminus j) - V(J)$, we can derive every supplier's utility as following: $u_1 = 213.07 - 215.32 = 2.25$, $u_2 = 8.85$, $u_3 = 5.88$, $u_4 = 19.45$ and $u_4 = 17.95$.

Table 1. A demonstrative case.

Supplier ID	Bid ($\hat{s}_j$, P_j^t)	Decision variable η_j	Payment p_j	Utility u_j
Supplier 1	(64.90,10)	1	67.15	2.25
Supplier 2	(24.15,50	1	33.00	8.85
Supplier 3	(27.12,6)	1	33.00	5.88
Supplier 4	(47.70,10)	1	67.15	19.45
Supplier 5	(33.00,5)	0	0	0
Supplier 6	(71.46,9)	0	0	0
Supplier 7	(49.20,8)	1	67.15	17.95
Supplier 8	(34.15,5)	0	0	0

4. Conclusions

Nowadays, logistics is an important part that provides fundamental support to promote transformation and upgrading of manufacturing enterprises. Thus, service-oriented LPSS is designed to help them transform and upgrade by the third party, the logistics product service provider company. Although manufacturers can benefits from LPSS, unfortunately it is hard to popularize LPSS. To address this problem, this paper introduces an intangible service, which is to allow manufacturers to share their idle logistics resources.

In this paper, we first present the concept of LPSS based on cloud manufacturing mode. Manufacturing enterprises are allowed to submit their idle logistics resource or requirement via a cloud platform in sharing manners. Based on this, the sharing logistics resources can be defined as an allocation problem in one-sided market, which consists of the company, a user and multiple suppliers (bidders). To address this problem, allocation model is established to determine the winners of suppliers and O-VCG auction mechanism is proposed to decide how much a user should pay for each winner. O-VCG mechanism properties are presented to prove its feasibility and applicability from theoretical perspective and a demonstrative example is also presented to show how it works.

Regarding the future work, this paper can be extended from one-sided market to two-sided market. Obviously, allocating idle logistics resource in two-sided market can further improve allocative efficiency and save time. Secondly, multi-attribute can be considered into model and mechanism. This makes allocation more practical and efficient. Finally, other intangible services can be designed to attract manufacturing enterprises to accept LPSS easily.

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