

Limitations and opportunities in e-platforms for the additive manufacturing market

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Abstract The expansion of additive manufacturing (AM) has led to an imbalance between supply and demand. As a result, e-platforms have emerged as an efficient means of coordinating the AM market. This work aims to review the primary references proposing e-platforms for matching and allocating AM customers' orders to AM suppliers' resources and determining service prices. Specifically, platforms using auctions as market mechanisms are explored, and opportunities to further exploit the potential of auctions to coordinate the singular AM market are raised.

Keywords: additive manufacturing; e-platforms; auctions; market mechanisms

1 Introduction

Additive manufacturing (AM) is spreading across the industry to manufacture functional parts (De Antón *et al.*, 2022; Byskov and Vedel-Smith, 2023). Industrial companies are increasingly outsourcing the production of subcomponents to specialised AM suppliers. However, current AM services have noted a lack of coordination between supply and demand (Zhou *et al.*, 2018; Wu *et al.*, 2022). The highly customised subcomponents with detailed specifications that AM demanders request cause them to struggle to find suitable suppliers. At the same time, AM suppliers need to evaluate several order requests to check whether they can manufacture them profitably. All these activities result in high transaction costs for demanders and suppliers (Tsay *et al.*, 2018).

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Electronic platforms (e-platforms) —also known as online platforms or cloud platforms— have emerged over the last few years as a favourable environment for conducting business transactions of AM services (Yang, Chen and Kumara, 2021). They provide an appropriate framework for coordinating part requests from distributed customers with available resources from distributed suppliers. E-platforms can exploit such a decentralised market structure to coordinate supply and demand in a way that significantly reduces transaction costs and increases market efficiency.

This work aims to review the primary references proposing e-platforms for matching AM customers with AM suppliers and allocating the requested orders. In particular, platforms using auctions as market mechanisms to solve the allocation and price determination of AM services will be explored. As a result, some proposals for improvement will be raised to further exploit the opportunities of the singular AM market by leveraging the potential of auctions as market mechanisms.

2 E-platforms for the AM market

Two types of service system e-platforms have proliferated in the matching between AM customers and AM suppliers: decentralised platforms and centralised platforms (Pahwa, Starly and Cohen, 2018). Whereas platforms of the first type provide the meeting point where demanders and suppliers can engage in business transactions, platforms of the second type centrally determine the allocation of orders to suppliers. Centralised platforms usually also set the prices of services.

Proposals for decentralised platforms were the first to appear. With the AM market still in its initial stage, e-platforms focused on making it easier for customers and suppliers to find each other. In their works, Rayna, Striukova and Darlington (2015) and Baumann and Roller (2017) reviewed and listed the main platforms that aimed to facilitate the trade of AM services. Although decentralised platforms allowed to reduce search costs, negotiation and selection tasks were still left to market participants. These activities entailed high transaction costs, and the situation worsened as new entrants joined the AM market.

Centralised platforms then started to emerge as a better option to increase the efficiency of the AM market. These platforms leverage information from distributed agents to make efficient market allocations. Specifically, centralised platforms employ market mechanisms to allocate part orders requested by customers to suitable AM suppliers (i.e., allocation) and determine the service prices (i.e., pricing). However, although centralised platforms always solve the matching and allocation between supply and demand, it is observed that not all platforms set prices for AM services. More production-oriented platforms focus mainly on the allocation —and usually also on the scheduling— of tasks to resources. On the other hand, more market-oriented platforms address both the allocation and pricing of AM services. Table 1 summarises the primary references of AM centralised platforms since 2017 and shows whether they deal exclusively with allocation or also consider pricing.

From the earliest proposals, it has been common for centralised AM platform designs to have been linked to the Cloud Manufacturing (CMfg) paradigm. CMfg platforms usually have a production-oriented focus and only delve into allocating orders to resources, thus leaving aside pricing issues (Framinan, Paz Perez-Gonzalez and Victor Fernandez-Viagas, 2022). Most of the reviewed references presented CMfg-AM platforms focused on allocating and scheduling AM tasks. Nevertheless, the table shows four platform proposals addressing allocation and pricing for an AM market. Stein, Flath and Walter (2020) introduced a heuristic mechanism to balance the capacity mismatch between AM manufacturers while improving social welfare. The other three proposals (i.e., Pahwa, Starly and Cohen (2018); Mashhadi and Salinas Monroy (2019), (2020)) employ auctions as market mechanisms.

Table 1 Primary references of AM centralised e-platforms

Reference	Allocation	Pricing	Auctions
(Zhou <i>et al.</i> , 2017)	√		
(Zhou <i>et al.</i> , 2018)	√		
(Pahwa, Starly and Cohen, 2018)	√	√	√
(Liu, Liu and Zhang, 2019)	√		
(Chen, 2019)	√		
(Mashhadi and Salinas Monroy, 2019)	√	√	√
(Luo <i>et al.</i> , 2020)	√		
(Ma, 2020)	√		
(Mashhadi and Salinas Monroy, 2020)	√	√	√
(Stein, Flath and Walter, 2020)	√	√	
(Liu <i>et al.</i> , 2021)	√		
(Yang, Chen and Kumara, 2021)	√		
(Cui <i>et al.</i> , 2022)	√		
(Wu <i>et al.</i> , 2022)	√		
(Zhong <i>et al.</i> , 2022)	√		
(Zhang <i>et al.</i> , 2022)	√		

3 Limitations and opportunities of auctions in AM e-platforms

Auctions are market mechanisms that can efficiently solve allocation problems in decentralised market environments (Gao *et al.*, 2022). They allow for combining the coordination advantages of centralised processing with the decentralised information and incentives from distributed agents (McCabe, Rassenti and Smith, 1991). Auctions have been used successfully to manage markets in a variety of e-procurement systems, including cloud computing (Kumar *et al.*, 2017), electric vehicle charging (Rigas, Ramchurn and Bassiliades, 2015) or truckload transportation

(Acocella and Caplice, 2023). An e-platform supported by an auction mechanism can solve allocation and pricing in a welfare-enhancing way.

In their work, Pahwa, Starly and Cohen (2018) first proposed a mechanism similar to a reverse auction in which bidders request AM orders and place bids showing the amount of money they are willing to pay. On their side, AM suppliers report their threshold prices for accepting the manufacturing of the orders. The platform then solves the allocation and pricing of orders with the information gathered. Similarly, Mashhadi and Salinas Monroy (2019) presented a mechanism consisting of a two-phased auction in which first, buyers are assigned printing area capacity (that they can use to schedule their own demand orders) according to their bids; then suppliers are assigned the correspondent orders. Later, Mashhadi and Salinas Monroy (2020) refined their auction mechanism with a deep neural network to increase the utility generated by the AM platform in the allocation and pricing.

While the works reviewed propose good mechanisms for efficiently stimulating the AM market, some points for improvements can be identified:

- i) The supply side is too centralised. Only buyers actively place bids in these mechanisms, whereas suppliers report their production costs. This fact prevents suppliers from competing in the market and seeking self-maximising strategies.
- ii) The possibility of combining orders from different buyers is not considered. As in many AM techniques higher resource utilisation can be achieved if multiple heterogeneous parts are produced in the same build cycle (De Antón *et al.*, 2020; Zipfel, Neufeld and Buscher, 2023), giving suppliers the opportunity to combine part orders from different buyers should increase market efficiency.
- iii) Private information from agents must be revealed. The design of these auctions requires buyers to disclose their reservation prices and suppliers to disclose their production costs to allow for efficient allocation.

Auctions have several variants that adapt to different market settings according to their properties. Consequently, a proper auction design should effectively address the three limitations noted. Over-centralisation of the supply side (i) can be dealt with in a double auction setting that allows both sides of the market to submit demand or supply bids. An auction allowing combinatorial bidding (i.e., a combinatorial auction) would give suppliers the opportunity to increase the productivity of their AM machines by bidding for the most efficient combinations of orders (ii). Moreover, an iterative combinatorial auction design would also allow reaching an efficient allocation without agents disclosing sensitive information (iii).

After reviewing the proposals of centralised platforms for an AM market and highlighting the main limitations of their market mechanisms, it seems an excellent opportunity to explore the design of an auction mechanism that fully considers the specific characteristics of the AM market. An auction design based on the double auction and combinatorial auction variants conceived within an iterative procedure could address all the issues raised and provide an efficient market solution.

4 Conclusions

As AM is expanding and an unbalance between demand and supply has been noted, e-platforms appear to be a more efficient means of coordinating this market. A review of the main works proposing centralised AM platforms revealed a clear bias towards efficient allocation of orders as opposed to price determination. Still, the few proposals of platforms addressing both the allocation and pricing of AM orders mainly employ auctions as market mechanisms. In this work, the features of these proposed auction mechanisms have been reviewed and some opportunities have been raised to further exploit the potential of auctions as a coordination mechanism for the singular AM market.

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5 References

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