A Vision for a Highly Automated Digital Local Manufacturing Network: Solutions and Challenges

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A Vision for a Highly Automated Digital Local Manufacturing Network – Solutions and Challenges

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Abstract. There is a lot of evidence of the manufacturing strategy shift from mass production to the individual and decentralized micro-production, which in essence means a shift from low-cost country production to production at the place of consumption. This paper presents a vision for a highly automated digital urban manufacturing network, based on a central market mechanism for matching designers, customers, and producers operating digital-manufacturing machinery. The mechanism proposed automatically clears the market by matching supply and demand, based on pre-given or auction-based bids with an optimal allocation. Contracting, profit-sharing and settlement are automated according to pre-specified market rules. Network participant profiles are used and updated to establish reputation and trust that are used in the allocation optimization. This paper presents the elements and logic of an automated digital urban manufacturing network on a technical level and discusses some of the benefits reached by shifting centralized production to decentralized urban networks in a wider perspective. Practical implications to the real-world industries, where the presented vision is relevant are shortly discussed.

Keywords: Digital manufacturing, platformization, automatic contracting, optimal allocation, digital twin

1. Introduction

Industry 4.0 can be described shortly as a new digitally-driven manufacturing paradigm that is based on the efficient use of smart machines steered by massive amounts of data [1]. According to Li [2], in the center of Industry 4.0 is the integration of new technologies such as Additive Manufacturing (AM), cloud computing, Internet of Things (IoT) with people and with products. Four important disruptions that face the manufacturing industry can be summarized as: i) the increase of data volumes; ii) analytics and business intelligence; iii) human-machine interaction; and iv) the ability to transfer digital information to the physical world [3]. In vein with the industry 4.0 paradigm (or manufacturing 4.0) that follows from it, this paper sets out to discuss manufacturing systems that are highly digitalized and that are based on a high level of digital automation. The discussed systems reside within the areas of the second and the fourth types of disruption identified.

Within the realm of highly digitalized manufacturing systems and network of systems, each machine- or system-instance can be understood as a unique cyber-physical system (CPS) that has both a physical part and a virtual-counterpart that exists as a node in "cyberspace" – in other words, the tangible machines are mapped in a virtual model-space that maps the physical reality with high fidelity and enables the fully digital and automatic (machine-initiated) information flow between system nodes. This refers to the type of constructions, often enhanced with real-time data connections and asset-specific life-cycle data-management, referred to as Digital Twins [4]. Typically, digital twins depict equipment inside single factory premises and are in place to form efficient cyber-physical production systems (CPPS) by combining separate CPS-entities into a system model with the goal of operating the system with high technical and economic efficiency. Most often the complexity in the modern digital twins is reduced by the static nature of the set-ups - the system configuration changes are kept to a minimum or are not allowed. According to Oztemel and Gursev [5], there are already, multi-company initiatives, such as Industrial Internet Consortium from 2014, which aim to bring together operational systems and digital technology to the widest possible extent.

Now, we leverage the thinking behind the digital twin and combining cyber-physical systems in the context of manufacturing 4.0 to the broader view of the interoperation between digitally operating agents that represent the demand and supply of manufacturing goods and the presented envisioned case is that of a fully digital market mechanism for products manufactured directly from digital blueprints. The vision differs from what can be already found existing through “hubs”, ideas of fully automated “dark” factories (see, e.g., [5]) or digital marketplaces/platforms for additive manufacturing in that the operations are conducted without human involvement in the operational phase (while the system allows for manual access also) between digitally operating machines through the digital market mechanism. The point of reference here is the concept of “local manufacturing” or “urban manufacturing”, which refers to fleets of digital manufacturing facilities operating near customers and not necessarily within “factory” environments. See Fig. 1 for a high-level sketch of a digital market mechanism. As the demand is digitally managed and, if demanded, routed to the production nodes closest to the demand there are consequences not only to manufacturing and to matching supply with demand, but also, and importantly, to supply chains and to what can be called “market positions” of agents in both the supply and the demand side. Importantly digital platformization of manufacturing may drive market power to the platforms in a similar way that has happened with the well-known platform businesses that have “captured” the retail markets of many standard goods internationally. Such platforms will disrupt also the value chains and the accumulation of value between the producers and the platform and thus will affect also the global manufacturing value chains (GVCs).

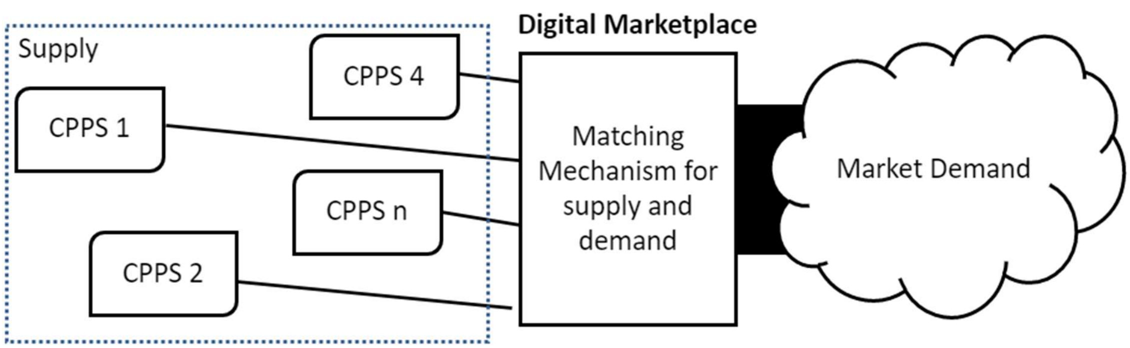

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Fig. 1. A high-level illustration of the digital market mechanism

The change brought by the change to local production and smaller manufacturing units has been acknowledged in previous literature. Despite the ongoing technical progress in the individual machine-to-machine communication protocols such as OPC-UA [6], the literature is lacking accounts on how to coordinate such systems in a way that would, even in theory, come close to the economics provided by the current paradigms of mass manufacturing. Here we address the question of how costs of networked small-scale manufacturing units can be brought down by proposing a centralized and automated digital market mechanism that can be used in efficient and dynamic coordination of a network consisting of multiple production nodes operating fully digitally and treating the network as a source of a large production capacity of goods. If the digital coordination is highly efficient the difference between single node high capacity and multiple node low-capacity network is made smaller.

Täuscher and Laudien [7] define marketplaces as platforms that enable and support transactions between independent supply and demand-side participants. They observe that the winner-takes-all dynamics of marketplaces have attracted hundreds of firms to launch their own marketplaces. The research on eCommerce and its´ many forms are already active for more than three decades and a community of researchers in the Information Systems Science domain has contributed to the topic. While the “talk” is about a market-mechanism, or a market-place, the same issues have also been discussed in the supply chain literature. According to Mentzer et al. [8] supply chain can be defined as a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer. They have further identified three degrees of supply chain complexity: a “direct supply chain,” an “extended supply chain,” and an “ultimate supply chain.” An ultimate supply chain includes all the organizations involved in all the upstream and downstream flows of products, services, finances, and information from the ultimate supplier to the ultimate customer. When we discuss a fully digital matching of supply and demand, for the sake of simplicity, we leave out the supply chain issue, while it underlies the production side of the equation. On a further note, it has been understood for a long time that global supply chains are in fact dynamic networks of interconnected firms and industries – this notion rings a familiar tone with what is proposed here.

Analytics in this context can be categorized as Big Data Business Analytics (BDBA) which will provide means to gain value from ever-growing massive amount of data [9]. With big data, analysis of the data is concentrating on the following qualities: velocity, variety, and volume [10]. This is then combined with business analytics where analysis is more concentrating on descriptive, predictive, and prescriptive analytics [11]. In manufacturing context with BDBA one can improve the visibility, flexibility, and integration of CPPS networks. Predictive and prescriptive analytics are in a key role in guiding companies to make solid decisions on the strategic directions [12]. Through BDBA we can evaluate CPPS networks through evidence-based data, predictive forecasting, mathematical modelling, operational and statistical analysis and through simulation and optimization techniques [9]. The systems required for the envisioned mechanism include the smart ability of splitting and matching demand with supply in an optimized way – the problem may seem trivial, but the difficulty grows with the number of network nodes included and if large orders must be split between multiple production nodes.

All in all the next presented vision is a product of combining the real-world digitally operated manufacturing units with the concept of digital twins brought to the context of clearing supply and demand within a concentrated market mechanism that can operate quasi-autonomously. As so far always, human is in the loop in that most decision-making, pre-approved or not, has at some point landed at a human desk. Next, we present the vision, then some conclusions are drawn and future research directions discussed.

2. Vision for an Automated Digital Local Manufacturing Network

The vision presented here is based on a marketplace-mechanism that intelligently and automatically matches the demand for local manufacturing with the supply. The type of products that are described are standard and ready-made designs with material specifications included, for example spare parts for existing machinery within a given context (industry). The vision is based on the notion of having a digital product store that lists, with pricing and other information the products available for purchase (Design store/depository in Fig. 2). The demand is of the type "product + quantity" and may include specification of speed at which the ready product must be delivered at the latest and must include the maximum acceptable price and may specify other requirements, for example the "reputation" required of the production nodes. Also, if there are requirements for "risk management" in terms of splitting large orders between multiple production nodes, such operations can be done either within the envisioned system or at the demand end. At some point, the credit of the demanding agent is checked (if not pre-approved).

The store is at the same time a depository of designs that are typically owned by the designer and that are used in the production of the products by the production nodes. Often the designers are owners of production nodes. Proprietary designs (for which the rights remain at the designer) can be added to the store by the design nodes and must include standardized information that is common and available for all designs. In a modern digital store-environment, products (here designs) will have a rating system that allows those who have bought the designs to rate them. The above-described design sharing constructions have been already implemented in the hobbyist 3D-printing online platforms [13]. In the case of the fully automated system proposed here, it must be able to distinguish between the design rating and the rating of the production node that has manufactured the design – both will have a separate rating of their own.

As the price of a given product is relative to each producer and the quantity purchased the pricing information is of high relevance in the store. Each production node must provide information about their node-specific capacity (quasi-real-time) and pricing (or pricing as a function of the quantity and delivery speed) for each design/product they are ready and able to manufacture to the store. The information is considered binding that is, non-negotiable and pre-approved by the production node; this is required for the market-mechanism to function properly. Also, the delivery information and cost for each production node must be considered ex-ante – this is now for the most part trivial, but if high quantities are demanded or demand is for delivery on short notice, the orders may have to be split between production nodes, causing a combined logistics-cost calculation to take place.

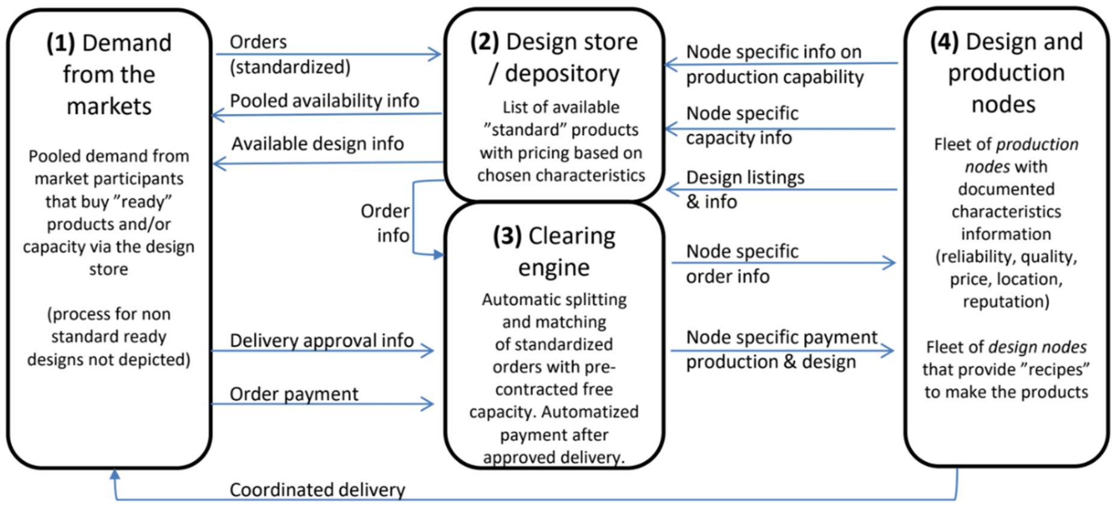

Fig. 2. Blueprint for a matching mechanism in a digital marketplace for the coordination of supply and demand for local manufacturing of standard products.

The orders (demand) and the supply are matched by the system (Clearing engine), as shown in Figure 2, and if necessary, automatically split between the production nodes. After the matching of the order, the node-specific orders are created and matched with the necessary designs that are fetched from the store and relayed to the production nodes. In a highly automated configuration, the designs may even be automatically placed on a production queue of a modern additive manufacturing unit. Some issues with the proprietary designs remain, for example, how can one ensure that designs are not misused by the production nodes after they are received. Encryption of designs and on-demand automatic decryption of designs within the production devices or other ways to solve digital-rights issues in this context are interesting issues – for as long as good universal answers to these problems exist, trust remains a key issue within local manufacturing networks.

Payment of goods takes place according to a pre-approved schedule that may be based on triggers such as the delivery of goods (partly or fully), or on time-based tranches. The payment for the use of the designs may or may not follow the schedule for the payment of products. Payment can also be contingent on the delivery, in which case information on delivery will trigger payments. Pre-approved contracting and payment scheduling allows fully automated transactions to take place after triggering information is provided to the system.

3. Summary and conclusions

In the context of digital local manufacturing, data in various forms is the key commodity. The driver is the information about the demand that can be attracted if a well-functioning and reliable network for standardized product delivery is in place, in other words, when a credible marketplace for acquiring the demanded goods and services exists. In the modern world of business, the marketplace is typically digital. What we know of digital business in general holds also for the digital manufacturing business: smooth access to the marketplace, standardization of products and payment are key underlying factors for success, knowledge of the existence of the marketplace is pivotal for the demand to gather around it, and trust in many forms drives the business. The owner of the marketplace is the owner of the information and thus sits on a valuable commodity that can be used to create additional value in many ways.

If the evolution of digital marketplaces for 3D-printed products and additive manufacturing services will most likely concentrate at first around specific industry areas in a way that designs and products for the area are available via a given marketplace. The marketplaces may be driven by specific industry participants in collaboration or by third parties that even represent the demand. In a modern industrial environment, the demand for the envisioned system can, for example, be driven by a sufficiently large set of predictive maintenance driven facilities, where the demand is generated by the need to replace worn parts in the facilities – in such cases, the orders can realistically (and in line with the vision) be automated and handled directly by the predictive analytics systems [14]. In such a case the marketplace could, for example, be run by the maintenance-providing agents. A next step in the evolution of the marketplaces may be a similar type of consolidation that has been seen with established platforms, where various groups of "contexts" are represented on a single platform – sold items ranging from books to healthcare products, from collectibles to machine tools. The consolidation may be driven by platform technology or by excellent marketing and "making the platform known" – the platform that everyone knows will get the most demand traffic, which in turn will cause it to be most desirable from the point of view of the supply-side actors.

The platformization of digital manufacturing means that those that are early adopters of successful platforms may come out of the game as winners, also standards within winning platforms in terms of manufacturing technology and various other issues such as delivery and quality terms, may become overall de facto industry standards, which inevitably will also affect device manufacturers who are in no uncertain terms forced to adhere to standards or provide multi-standard devices. Digital interfacing will become more important than before – machines that are unable to communicate with the platform are losing out on business or must be converted via a "translator" to gain access – costs will be incurred in such cases. Pricing is driven down as happens in markets, where numerous competing actors are providing services – high-quality high-reliability service providers with good reputations, a connotation for trust, may reap higher added value.

The implications of the autonomous machine-to-machine digital information-based market mechanisms as discussed above are not known. What the demands of such mechanisms for contracting, cryptography, supply chain- and risk management are, is still an open question. What we know from past research helps to formulate relevant hypotheses and guides us forward, but what the most important specific challenges and drivers are remain unknown.

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