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Demand-supply matching through auctioning for the circular economy

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Abstract

The circular economy aims to reduce the consumption of resources and energy by exploiting multiple use-cycles of components and materials. The creation of new circular businesses hinges on efficient alignment between market demands of circular products with the supply of End-of-life components and materials. In this paper, we address the digitization of a matchmaking tool for the circular economy by defining demand-supply matching (DSM) in context of business link identification and cross-sectorial matchmaking. We further specify a DSM process and present our DSM tool, which facilitates publication and search for supplier offerings and demander needs, selection of auctioning candidates, and digitized auctioning and contract definition. By that, this tool supports the alignment of market demands with matching supply offerings. In particular, it combines the steps of publishing, searching, selecting, auctioning and contract definition into one tool, which we argue can make matchmaking more efficient compared to addressing these steps separately. Finally, we present the design of the tool and discuss its merits in light of the needed acceptance for automating business link identification and contractual interactions.

Keywords: business link identification; demand-supply matching; contractual agreements; circular economy; auctioning; cross-sector collaboration

1. Introduction

The circular economy principle, formalized by the Ellen MacArthur Foundation [12], aims to reduce the consumption of resources and energy by exploiting multiple use-cycles of components and materials in new products with high added-value through product reuse, repair, re-manufacturing and material recycling. Thereby, it has the potential to significantly reduce the input of raw materials and energy in manufacturing, leading to a more sustainable future [14]. Korhonen et al. [11] state that circular economy should limit the throughput flow to a level that nature tolerates in terms of natural reproduction rates, while generating new business opportunities for companies. One essential success factor for such new business models is to align market demands of circular products with the supply of old and used products in the return flow [15]. The question is, ***can such alignment be improved and made more effective through digitization for easier identification of new business opportunities and the realization of those?***

In this paper, we address the digitization of a matchmaking tool for the circular economy. The objective of the tool is to match demand and supply of components and materials across multiple industrial sectors, e.g. on batteries, mechatronics and electronics, composites and technopolymers, and textile. The demand-supply matching (DSM) tool should enable matching suppliers of End-of-Life (EoL) components and recycled materials or logistics companies with demanders such as remanufacturers, demanufacturers and material re-processors. To enable such matching, different suppliers in the circular value-chain need to ***publish*** their products and services with information relevant for the matchmaking. Demanding parties can then ***search*** for offerings that matches their needs, and seek to establish new business links. This process can of course be reversed so that demanding parties publish their needs and suppliers search for such that matches their offerings.

When a match is found, the identified business opportunity need to be realized. This means to turn the identified opportunity into business by ***agreeing*** on price and other terms relevant

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for the desired trade. Such agreement need further to be captured in a ***legal contract*** and signed by the parties subject to the trade. Should more than one partner match the search, the establishment of the legal contract should be preceded by a ***auction***, to achieve a market equilibrium. In addition to the publishing of needs and offers, the DSM tool aims at digitizing also the auctioning, contract definition and signing steps to truly make efficient the alignment of market demands of circular products and material with the supply of old and used ones.

The DSM tool is to be part of the federated platform developed in the DigiPrime project [26]. This project aims to develop a circular economy digital platform in order to create and boost circular business models based on the data-enhanced recovery and reuse of functions and materials. Specifically, it will create and operate a federated model of digital services for cross-sector businesses in the circular economy.

Auctioning based on distributed ledger technologies (DLTs) has been extensively studied in recent years, e.g. in the context of cloud resource allocation and for vehicle-to-everything (V2X) communication subject to negotiations of various kinds [23, 24, 25]. Issues related to fairness, accountability and auditability are addressed with support of DLTs. Like those works, the DSM tool is inspired by DLT principles and aims at using those to providing auctioning for the DigiPrime federated platform, including the unforgeable and immutable storage of both intermediate bids and cryptography signed agreements.

The scope of this paper is the definition of the DSM tool, its basic operational flow and component architecture, including interactions between internal components and instances of the distributed architecture in context of the DigiPrime federated platform. Out of scope is the evaluation of the tool as well as its possible use in various demand-supply matching use cases.

Our ***main contributions*** are; (1) the definition of DSM in context of business link identification and cross-sectorial matchmaking for the unlocking of new business opportunities, (2) the specification of a DSM process for the identification of potential business partners from which auctioning candidates can be selected, and the (3) design of our DSM tool featuring (a) publish and search for supplier offerings and demander needs, (b) selection of auctioning candidates, and (c) digitized auctioning and contract definition.

The remaining of this paper is organized as follows: In Section 2, we discuss business link identification and our DSM process. In Section 3, we present our design of the DSM tool in terms of its architecture and internal structure. Lastly, in Section 4, we discuss our contributions in light of their significance for the circular economy and end the paper with our conclusions.

2. Demand-supply matching

To understand the importance of our DSM tool, it helps to look into recent trends in resource efficiency and barriers to entry in the circular economy. The benefits of reverse logistics and circular value streams has been apparent for decades. The last two decades have seen a sharp rise in commodity prices and increasing price volatility [18]. Material recovery along the value chain can be an effective tool in driving down costs related to manufacturing and has an estimated potential to save up to 630 billion Euro p.a. at the EU level alone [13].

The average rate of circularity of the EU in 2017 was 11.2% [19]. Barriers and challenges that currently exist include economic and organizational barriers. A survey of mostly European re-manufacturers [20], for example, showed that staying profitable, access to cores, and a lack of customer awareness are some of the most pressing economic challenges in re-manufacturing. Moreover, relevant data to make product recovery management decisions is often diffuse along the supply chain and difficult to find [21]. We aim at tackling such issues by providing an effective DSM tool to efficiently connect parties across various sectors.

2.1. Business link identification

To implement an effective DSM tool, the identification of potential business links is fundamental. Hence, a deep analysis of different value-chains is needed. This has been done starting from the different pilots present in the DigiPrime project, focused on the following sectors: Lithium-ion batteries, mechatronics and electronics, composites and technopolymers, and textile. E.g, considering the composites circular value-chain, several stakeholders act as waste owners, waste managers, designers, recycling companies and composite manufacturers. This circular value chain goes beyond the traditional composites users. The focus of this pilot is to promote the closed-loop recycling of composite materials and their reuse in new high-added value applications, following a cross-sectorial approach driven by material quality.

The DSM tool is of interest for all the above-mentioned actors and sectors. As an example, a composites waste owner could offer its EoL products to recycling company but also to designers of new products embedding recovered material. In turn, the designers could search for a material satisfying their requirements, but also of composites manufacturers with specific capabilities and technologies. Every actor in this value-chain could offer their products and services to others making it possible to search for them. For this reason, the definition and configuration of the match-making algorithm has to be based on the deep analysis of the value-chain and on the consequently most interesting characteristics of material and products.

The DSM tool entails the presence of a search and publish functionality; where businesses can publish an offering, while others can search based on their needs. This functionality is present in marketplaces within industrial sectors with established circular routes, e.g. remanufactured products within the automotive sector. Lately, efforts have been made towards a cross-sectorial marketplace for circular businesses. Austin Materials Marketplace brought together businesses and entrepreneurs within the online exchange platform with the goal of finding value in discarded material and implement industrial ecology at inter-organizational level [17].

Zaoual et al. (2018) [16] realized the need for third party matchmakers to ensure the implementation of industrial ecology between organizations. They tackled three case studies of eco-industrial networks in Denmark, Canada, and France. Four strategic activities for matchmakers were highlighted: “revealing value in industrial ecology, generating trust, activating industrial ecology, and institutionalizing industrial ecology." The DSM tool tackle these barriers by digitizing publishing, searching, selection, auctioning and contract definition within the DigiPrime platform. With the aid of this tool, new business links between industrial sectors can be showcased.

2.2. Matchmaking Structure

The DSM process is depicted in Fig. 1. It illustrates the search, filtering and auction initiation for re-manufactured composite material. It is assumed that a database with published capabilities of suppliers already exists, and a match is to be made between customer and supplier. Firstly, the user state the search type (suppliers), reference sector (composites) and type (polymer) to initiate a query for the needed material.

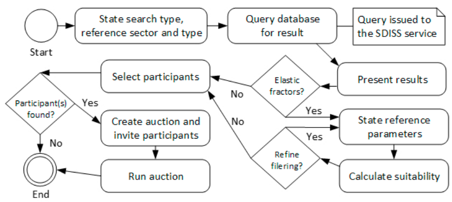

Fig. 1. Matchmaking process flow

The query result is presented to the user, which decide on whether to filtering the result or instead consider the complete search result. Filtering include to state reference parameters, e.g. fiber length, location, and other properties associated with the material. Some reference parameters may be elastic, e.g. the location could be considered an elastic requirement with preference for material located closer to the customer. In general, elastic requirements are variable and consist of a range of suitable values, whereas inelastic requirements have to be exactly same when matching distinct parties. Filtering with elastic requirements results in a ordered list with suitability scores representing the stated elastic requirements. With filtering, suppliers that do not meet inelastic customer requirements are not considered, whereas elastic requirements are individually compared with the suppliers' capabilities and are assigned a suitability score based on how close they are to customer requirements (Section 2.3). This suitability score influences order of listed results. After suitable parties have been listed, the user can select from the lust and create a new auction (Section 3).

2.3. Calculating Matchmaking Suitability

For the DSM tool, suitability is assumed to be the 'closeness' of two ranges of values proposed by two distinct parties in the matchmaking framework. The suitability of a demand-supply match is calculated for elastic requirements. This calculation has been adapted from calculations of Marginal Reuse Rate by Umeda, Y. et al. [22]. Despite being applied in a different context (returns over time periods), the paper provides a useful method of finding concurrency of functions.

The calculations of suitability is done by assigning each elastic factor a certain Suitability Index SI_i. For this, α_i is assumed

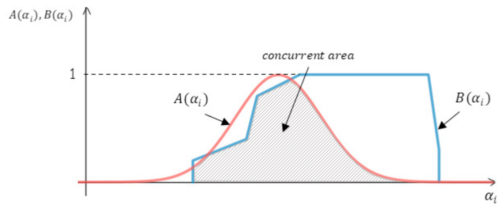

Fig. 2. An example of possible customer ($A(\alpha_i)$) and supplier ($B(\alpha_i)$) functions along their range of α_i

to be any possible value of the elastic factor i, for example quantity of material. Now, $A(\alpha_i)$ and $B(\alpha_i)$ are assumed to be functions representative of the suitability or the availability of quantity α_i along its range of values for the customer and the supplier respectively, and therefore run from 0 to 1, with 0 being unsuitable and 1 being completely suitable. Now, the concurrence of the functions can provide a good measure of SI_i as:

$$SI_i = \frac{\int_0^\infty min(A(\alpha_i), B(\alpha_i))}{\int_0^\infty A(\alpha_i)} \quad (1)$$

In Equation 1, $min(A(\alpha_i), B(\alpha_i))$ stands for the smaller value between $A(\alpha_i)$ and $B(\alpha_i)$ and is indicative of the concurrence of the functions. The denominator is a scaling factor. An example with two exemplary functions is provided in Fig. 2 The application of this equation to all measurable and variable factors $i...n$ yields a total 'Suitability Score' of a supplier. This score is then compared among other relevant suppliers.

3. Multi-party negotiation and auctioning

3.1. Digitized contractual interactions

Business-to-business (B2B) negotiations are generally subject to contractual agreements capturing rights and obligations associated with traded services or goods. The contracts established are typically connected to a selected legal dispute resolution system, such as a court of law. Based on the adjudication of the selected court, the associated police force can provide enforcement. When digitizing this type of negotiation, we need to ensure that contracts are established using the required legal prose and are properly signed. In addition, we want to make sure that the signed contracts are not altered afterwards, making them inconsistent with the agreements they capture.

3.2. Bi-lateral negotiation

Palm et al. have studied the digitization of bi-lateral contractual negotiations [1, 2], i.e. trade, and defined the Exchange Network (EN). EN is a general-purpose and implementation-independent concept model and architecture for digital negotiation and non-repudiable exchanges of services and goods subject to trade. In later work, the use of Ricardian contracts is included in this architecture [3]. Such contracts consist of regular legal prose and machine-readable parameters [4].

With EN, negotiations are based on a state machine that captures the steps to make offerings and counter-offerings to reach an agreement accepted by two negotiating parties (Fig. 3). The "offering" step includes for a party A that receives an offer from another party B to evaluate it and determine if the offer should be accepted, rejected or that a counter-offer should be issued. Should a counter-offer be issued, party B may decide to accept, reject or issue another counter-offer. In case of repeatedly issued counter-offers, this process goes on until either party rejects or accepts (or until a counter-offer expires).

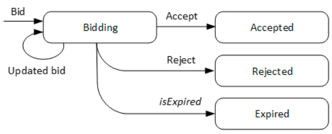

Fig. 3. The Exchange Network (EN) state machine

The EN architecture supports different implementations, ranging from centralized deployments that relies on a by all trusted party that keeps an unforgeable and immutable log of established contractual agreements, to an entirely decentralized implementation with a by all participants replicated such. Implementing a replicated log of contractual agreements brings advantages in that negotiating parties do not need to fully trust each other in keeping this log, nor trusting a third party.

The implementation of EN do not require any consensus mechanisms like those typically provided by DLTs [5, 6, 7]. However, the kinds of tamper-proof ledgers facilitated by DLTs could be used for keeping the log of established contractual agreements conceptualized by the EN architecture. Possible implementations of EN based on R3 Corda [5], Hyperledger Fabric [6] and Etherium [7] are considered by Palm et al. [2]. They further present a simpler implementation based on signature chains, which relies on data structures that use signatures and hashes in a way comparable to blockchains.

The signature chains consist of a chain of records, each of which may refer to (1) a previous record and (2) a Ricardian contract. Each record is cryptographically signed by one or more attestors and any references to records are the cryptographic hashes of the data referred to [8]. A third party given a chain of records are able to verify that they have been signed by their attestors and were created in a certain order. This provides the desired properties of an unforgeable and immutable log of established contractual agreements.

3.3. Multi-party negotiation and auctioning

Auctioning can be done according to the EN state machine adapted for multi-party negotiations, i.e. auctioning. With auctioning, the "offering" step will have a different meaning. Instead of two negotiating parties evaluate incoming offers and decide whether to accept, reject or make a counter-offer, multiple offers need to be evaluated in relation to each other. In addition, for auctions with public bids, these need to be published to all parties that participate in the auction.

Auctioning based on DLTs has been extensively studied in recent years, e.g for cloud resource allocation [23, 24]. Moreover, Leiding et al. [25] have explored the use of DLTs for the V2X economy. They present a DLT-based V2X platform that enables a transaction and interaction layer for services and goods based on the concept of Vickrey Auctions where sealed bids are submitted and the winner pays the second highest bid. Our approach differs from this approach in that we aim at supporting also auctions with multiple bids from each participant, e.g. Scottish Auction with public bids and a known deadline.

3.4. The demand-supply matching (DSM) service tool

The DigiPrime federated platform architecture is designed for collaboration and information sharing between semi-autonomous decentrally organized businesses. As mentioned in Section 3.1, the EN concept model allow for an entirely decentralized implementation. Hence, we use the EN concept model adapted for auctioning as described in Section 3.3 to define the architecture for the DigiPrime DSM service tool.

The DSM tool provides a search and publish functionality as well as matchmaking. It may be used by DSM brokers of material and products that represents suppliers and demanders for them to move beyond their existing ecosystems in finding new business links in the circular economy. As an alternative to using an external DSM broker, the supplier and/or demander could themselves perform the tasks of the broker.

3.4.1. DSM architecture

In the DSM tool architecture (Fig. 4), each party may keep its own instance of the DSM tool. This facilitates auctioning in between parties that may not fully trust each other without relying on any trusted third party. The DigiPrime DSM system relies on a centralized database system, i.e. the semantic data infrastructure, search and sharing (SDISS) service, and a system for identity and access management (IAM).

The IAM system implemented with Keycloak [9] provides through single-sign-on (SSO) based on OAuth 2.0 [10] the user identity and authorization needed for the establishment of contracts based on signatures of authorized representatives for the involved parties. User authorization is supported by OAuth 2.0 access tokens brought by users when accessing the DSM tool service via the DigiPrime portal. These tokens are then validated by the DSM tool service with the IAM system.

The SDISS service is used as a repository to publish supplier offerings, demander needs and active auctions. Thereby, parties can search for offerings, needs and active auctions that matches their businesses according to the process depicted in Fig. 1. When auction-ready matches are found using this process, the user creates a new auction and invite the matching parties. Alternatively, the user may ask the owners of matching auctions already created to join those. Auctions of different types may be conducted, including Scottish Action with open bids and a known deadline at which the auction ends.

3.4.2. DSM internal structure

The *Behaviour engine* administers the token verification process with its internal *Token verification*, which may cache tokens previous verified with the *IAM system*. It also manages the search issued by users and filtering of results obtained from the *SDISS system* with its internal *Filtering system*. Once a auction-ready match is found by the user, it initiates the creation of a

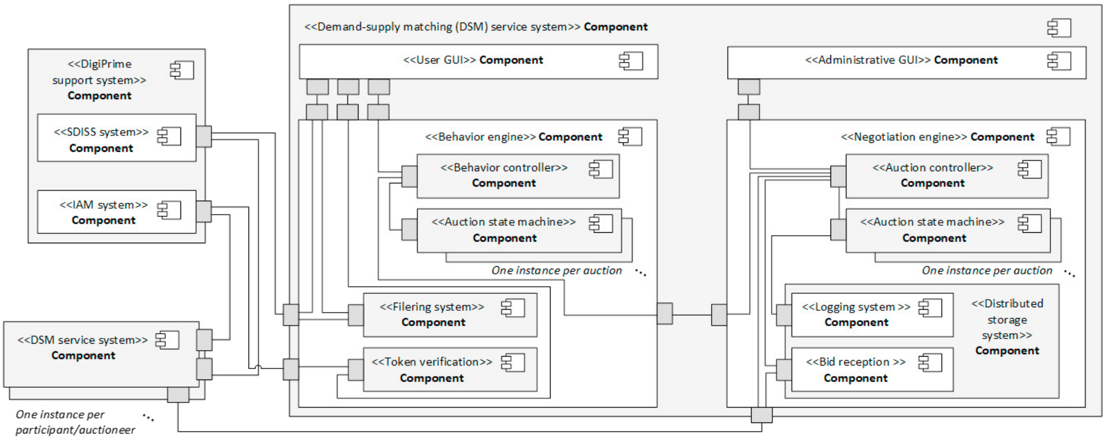

Fig. 4. The demand-supply matching system component architecture

new auction with associated invitations of participants with its internal *Behaviour controller*.

The creation of a new auction involves to instantiate a to the *Behavior engine* internal *Auction state machine* for the created auction, and to invoke the *Negotiation engine* for it to initiate the new auction and invite the selected participants. The *Behavior engine* will use its *Auction state machine* to keep track of the state of the auction as the auctioneer, including evaluating incoming bids and eventually select one or more winners (i.e. in case bids cover only part of the demand or offering subject to the auction). Upon an accepted invite, the participants will in the same manner instantiate their own *Auction state machine* components to keep track of the auction in question.

When the *Negotiation engine* receives a request for a new auction, it firstly instantiate a *Auction state machine* for the auction, and then issues invitations to participants with the other *DSM service system* components. The request from the *Behavior engine* to create an action includes the ID of the Ricardian contract subject to the auction and the ID of the auction type, e.g. ”Scottish Auction” with start date ”2021-03-19T07:22Z” and stop date ”2021-03-21T07:22Z”. These IDs are previously provided to the *Behavior engine* as they are created via the *Administrative GUI* of the *Negotiation engine*.

In an auction, signed bids are issued by participants, via their *User GUI* components, automatically based on bidding policies set and enforced by their respective *Behavior controller* components, or a combination of those. In case bids are issued automatically, the user e.g. can set policies for the maximum amount of money to offer for a certain quantity of products, volume of material or number of services to be delivered. These parameters can then be applied to a single auction, or a set of auctions to allow for participation in more than such on the same type of product, material or service. The *Behaviour controller* will then keep track of bids in all auctions subject to the policies and make bids in the different auctions according to the set policies.

Incoming bids are received to the *Negotiation engine* internal *Bid reception* component of the auctioneer, which is responsible of determining the order at which incoming bids arrive. Arrived and ordered bids are sent to the *Auction controller*, which sign those on behalf of the auctioneer. The *Auction controller* also evaluates the bids according the predefined auction type rules and update the *Auction state machine*. Moreover, the *Behavior engine* is updated as well for it to view the process to the auctioneer. When the *Auction state machine* of the *Negotiation engine* is updated, it calls the *Logging system* to store the new auction state, including all received bids. Moreover, it may publish new bids to all participants by sending that information to the *Negotiation engine* components of the participants (i.e in case of an auction type with public bids).

Similar to the EN signature chain implementation mentioned in Section 3.1, the *Logging system* calculate hash pointers for the Ricardian contract templates and associated name/type-value pairs, and the public key certificates of the agreeing parties. These hashes are cryptographically signed by the parties which thereby confirms the agreement and provide each other with the necessary proof of it to be used in case of a later dispute. The record capturing intermediate bids and the resulting agreement may further refer to a previous established such to ensure that also the order of related agreements are properly signed and stored in an unforgeable and immutable log.

4. Discussion and conclusions

In this paper we have defined demand-supply matching (DSM) in context of business link identification and cross-sectorial matchmaking, and specified a DSM process that facilitates the automated selection of candidates for trade or auctioning to unlock new business opportunities. We have further presented the design of our DSM tool, which provides digitized DSM through auctioning for the circular economy. The DSM tool shows how the market demands for circular products can be aligned with the supply of old and used products in the return flow. The tool combines the steps of publishing, searching, selection, auctioning and contract definition into one and the same tool, which we believe provides considerable more value than offering separate tools for these steps. For example, with the DSM tool the information published and searched for can be directly captured in the format of digitized Ricardian contracts. These can then be negotiated about, digitally signed as an agreement, and stored in an unforgable and immutable log shared among the agreeing parties.

The DSM tool remains to be evaluated with the pilot and use case owners of DigiPrime and other stakeholders in the circular economy. Maybe the bigger issue that may hinder its use is resistance against making contracts digital and automating negotiations aiming at establishing contractual agreements. Although our DSM tool will hardly come into commercial use in the near term, we believe that the demonstration of it plays and important role in helping actors start relating to digitized DSM for the circular economy. In any case, we conclude that the above-mentioned steps needed for DSM can be automated as shown with the DSM tool.

Presently the DSM tool is partly implemented to validate its design, while it remains to be completed and integrated with the DigiPrime platform for use with pilots and in use cases. The future work includes thus to make the DSM tool ready for experimentation on the different pilots and use cases of the DigiPrime project to validate its relevance and explore the willingness of various actors in adopting this kind of solution. This may also involve adding more features and functionality to the tool, e.g. to support additional auctioning models and to further automate the participant behaviors and thereby enable goal-driven use rather than manual selections and negotiations. Moreover, the scalabilty of the unforgable and immutable log shared among the agreeing parties need be examined as well as the further use of such records, e.g. to calculate key performance indicators (KPIs) for the circular use of products and material.

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