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Forming on-demand supply chain collaborations with evaluation of fit and risk

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Abstract

We outline a service that underpins formation of supply-chain collaborations. Companies can use the service to search for suitable partners with the objective of forming a collaboration with them. Such collaborations are intended to be built on demand — in response to complex business opportunities that may involve designing, manufacturing and delivery of a customized product and may therefore require capabilities and capacities that a single company may not possess. Potential collaborations are being presented to the user and their fit is being evaluated according to a range of criteria that include companies' capabilities, geographic locations, and other characteristics. In addition to the calculation of the fit implemented in the service, we propose in this work to evaluate the risks associated with the potential collaborations.

Keywords: digitization; digital platform; supply network; supply chain collaboration; matchmaking; risk

1. Introduction

Information and communication technologies have decidedly penetrated the way people, companies and institutions act. This transformation, referred often to as digitization, has at its core "collecting, processing and exchanging information in digital form, which ultimately makes it easier to connect businesses and people, access and exchange information, as well as convert it to useable knowledge" [1]. Digitization has a wide-ranging impact

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on business-to-consumer, business-to-business, and consumer-to-consumer relationships, and leads to creation of new business models and emergence of new marketplaces [2].

One of the major developments of digitization has become the emergence of online service platforms that allow individuals and businesses to share their unused or underutilized resources in a timely and efficient manner. Examples include ride hailing services like Uber and accommodation services like AirBnB. Such platforms create new opportunities for resource owners as well as their potential users by letting them find each other in an easier way and thus allow for better matching of supply and demand. This development, embracing a variety of different platforms, represents the recent shift towards 'sharing economy' [2, 3].

A parallel development amid the increased adoption of information and communication technologies has become the concept of Industry 4.0, which has emerged as a policy initiative aiming at digitization of production processes along the entire value chain [4]. Industry 4.0 sets focus on organizing production processes by the principles of interoperability between physical and cyber systems, decentralization, real-time data analytics, service orientation, and modularity [5] and thus enables digital integration across the value chain, self-adaptation of production systems, and agile response to customer demand for increasingly customized products [4–6].

Similar to the adoption of technologies that promote sharing economy via online service platforms, adoption of Industry 4.0 at the inter-firm level has the potential of letting various supply-chain members establish collaborations 'on-demand' [3] and dynamically share their production capacities and capabilities with each other. Such collaborations bring a number of benefits to the partners, such as a better capacity utilization and a better responsiveness to customer demand [6]. Dedicated online platforms may offer matching demand for production capacities and capabilities with their supply across participating companies. An example of such a platform is DIGICOR — which represents a technology platform offering "collaboration tools and services that allow manufacturing companies and service providers to create and operate collaborative networks across the value chain" [7].

Below we outline a service that underpins formation of supply-chain collaborations on DIGICOR, called Tender Decomposition and Matchmaking Service. Member companies can use the service to search for suitable partners with the objective of teaming up with them and tendering for complex business opportunities as a consortium of companies. Such consortia are intended to be built on demand — in response to a *call-for-tenders* that may request designing, manufacturing and delivery of a customized product and may therefore require capabilities and capacities that a single company may not possess. Potential consortia are being presented to the user and their fit for the job is being evaluated according to a range of criteria that include companies' capabilities, geographic locations, and other characteristics. In addition to the calculation of the fit implemented in the service, we propose in this work to evaluate the risks associated with the potential consortia.

The rest of the paper is organized as follows. In Section 2 we outline the DIGICOR platform and the existing implementation of the Tender Decomposition and Matchmaking Service in greater detail as well as discuss them in the context of related work. Section 3 explains the approach to risk evaluation adopted in the present work. Section 4 concludes the paper with limitations of the study and outlook for future work.

2. Background and related work

2.1. DIGICOR and Tender Decomposition and Matchmaking Service

The DIGICOR platform [7] comprises a set of loosely connected services that allow companies to register on the platform, specify their manufacturing and service capabilities in relation to specific products or product families, and also specify demand for certain products and services in the form of a call-for-tenders (CfT). Based on the CfT specifications and the structure of the requested product or service, the platform can look for prospective supply-chain collaborations among member companies that would be able to jointly meet the CfT requirements and provide the requested product or service. When such a collaboration becomes formed, the platform keeps track of its entire lifecycle and enforces governance rules. Apart from that, platform services include production planning and gateways to factory systems for maintaining access to shop-floor data, thus ensuring real-time visibility into the supply-chain operation [8]. DIGICOR sets a particular focus on integrating small and medium-sized enterprises (SMEs) into complex supply chains of Original Equipment Manufacturers (OEMs) — because SMEs, while generating a major fraction of the total value added in today's supply chains, may find it challenging to adopt Industry 4.0 technologies [6]. The platform is designed as an extensible system that permits addition of new services as well as 'unplugging' of existing services and running them in a standalone fashion.

Tender Decomposition and Matchmaking Service (TDMS) is a DIGICOR component that allows the user to build and evaluate prospective supply-chain collaborations via decomposition of CfT requirements and matching these with the capabilities of companies registered on the platform. TDMS is aligned with the microservices architecture of the DIGICOR, but it can also be deployed and run as a standalone service. The key functionalities offered by the TDMS include [9]:

1. *Ontology representation* of products, CfTs and companies' capabilities.
2. *Tender decomposition:* decomposition of CfT requirements into smaller tasks.
3. *Matchmaking:* matching tasks with companies' capabilities and generating potential consortia of companies that could jointly meet CfT requirements and submit a tender.
4. *Evaluation of fit:* evaluating the consortia towards their overall suitability for the CfT.
5. Specification of preferred consortium members for matchmaking.
6. Identification of gaps in prospective consortia.
7. Replacement of consortium members.
8. Matchmaking for product parts with the aim of incremental consortium building.
9. Checking the resulting consortia with respect to gaps and redundancies.

TDMS wraps up these functionalities in a graphical front-end implemented in Angular (v. 4). A TDMS demo is available online at http://130.88.97.225:4200 (username: TDMS@uniman.eu; password: uniman). We refer the reader to [6] for further details regarding the design and implementation of the front-end, with exposition of the user workflow in a flowchart and illustration of key functionalities of the service on screenshots. Section 1.7.5 of the DIGICOR Portal User Manual [7, *Training* area] offers a detailed description of other elements of the TDMS user interface. Apart from offering a graphical front-end, TDMS exposes a RESTful application program interface (API) for accessing the above functionalities in the back-end. TDMS API further allows the user to run TDMS as a standalone service, while utilizing its back-end capabilities only. We refer the reader to [9] for the detailed exposition of the API.

TDMS has been designed and developed in accordance with end-user requirements and end-user feedback of the aerospace use case of the DIGICOR. Therefore, some of its features reflect specifics and requirements of the aerospace industry. These features do not, however, impede application of TDMS in other industry settings either; [9] illustrates an automotive use case of the TDMS, in which it has been deployed as a standalone service.

Tender Decomposition and Matchmaking algorithm is used by the TDMS to provide its key back-end functionalities. The algorithm serves the main purpose of matching demand (represented by a specific CfT) with supply (capabilities of available companies), using the information stored in the ontology [6]. The algorithm comprises three main parts: tender decomposition, matchmaking, and evaluation. The first part is intended to decompose the target product of the CfT and associated goals into sub-products and sub-goals in a recursive fashion — using the information about the product structure from the ontology and following the rules of goal decomposition [6]. This potentially gives several *tender decompositions*.

The second part of the algorithm — matchmaking — attempts to find suitable consortium members for each generated tender decomposition among companies available in the ontology and distribute tasks between them according to their characteristics. This potentially gives several prospective consortia for each tender decomposition. The process is guided by a number of criteria. All criteria used by the algorithm are divided into three categories: (i) *inclusion criteria* — for filtering out non-eligible companies from the search based on their capabilities; (ii) *grouping criteria* — for gathering eligible ones into prospective consortia capable of jointly meeting the CfT requirements, and (iii) *evaluation criteria* — for evaluating the consortium's fit. The specific criteria used in the current implementation of the TDMS follow the end-user requirements of the aerospace use case of the DIGICOR [9]. The matchmaking part of the algorithm uses criteria from the categories (i) and (ii).

The third part of the algorithm — evaluation — assesses the prospective consortia towards their *fit*, or overall suitability for the CfT. This is accomplished by applying evaluation criteria from category (iii) and matching them with the requirements specified in the call-for-tenders — to evaluate the extent of coverage of those requirements by the consortium members, individually and as a consortium.

2.2. Related work

Several solutions related to DIGICOR have recently become developed as outcome of various research initiatives. The COMPOSITION project (www.composition-project.eu) aims to provide an ecosystem for collaborative manufacturing processes — both, within and between factories, capable to support Industry 4.0 exchanges between the actors. Similar to DIGICOR, it supports automated supply-chain formation through its marketplace framework, with the difference that this is achieved by means of a distributed multi-agent system through negotiations between the agents representing individual companies, so that the supply chain is being formed incrementally rather than in a holistic fashion. Similarly, the NIMBLE project (www.nimble-project.org) aims to create a B2B platform for supporting formation and operation of supply chains. It allows companies to expose their capabilities as well as discover other companies' capabilities, establish supply-chain relationships, and securely exchange data. It further supports business processes involving multiple parties, yet differently from DIGICOR, the search for partners takes place on the one-by-one basis. The vf-OS project (www.vf-os.eu) aims to offer an operating system for virtual factories that would support manufacturing and logistics collaborations between companies. It facilitates evaluation of prospective business opportunities by a consortium of companies as well as monitor the collaboration progress. Similar to DIGICOR, the potential business opportunity undergoes decomposition, yet the focus is set on serving a specified consortium of companies rather than discovering and evaluating prospective consortia.

Regarding the approaches proposed in the research literature, the analysis conducted in [6] further reveals that most existing approaches to supply-chain formation employ a variety of methods for supplier selection that are focused on identifying a single supplier for a single buyer subject to multiple criteria, whereas approaches identifying a consortium of suppliers are less common. TDMS is different in this regard, as it seeks to identify multiple prospective consortia for the given business opportunity. Further, it can perform multi-level decomposition of the business opportunity while doing so in a fully automated fashion. Furthermore, the prospective consortia are being automatically evaluated towards their fit to support the user's decision-making.

Nonetheless, TDMS lacks an essential feature for supporting such decision-making, which is the evaluation of risks associated with the prospective consortia. Risk evaluation should reflect vulnerability of the consortium to potential disruptions — which can be operational, such as equipment failure, supply shortages, and financial constraints at the consortium members, or geopolitical, such as natural disasters, terrorism, political instability, trade wars, strikes and, more recently, pandemic outbreaks [10–13]. Due to interconnectivity between the members of a supply-chain collaboration, disruptions can propagate throughout the supply network [10, 13]. Therefore, evaluating the risks associated with a supply-chain collaboration requires taking into account both, its individual members' exposure to risk and the structure of the underlying supply network [10, 11].

Current literature offers a variety of approaches to quantification of risks in supply chains. Many of these assume an existing supply network and/or knowledge of operational-level data and decisions, such as inventory levels and order policies. Examples include evaluation of a risk-exposure index in the automotive industry [14], a stochastic programming approach to location, allocation, and inventory management decisions in supply network design [15], a supplier selection and order allocation approach [16], and a Bayesian network approach to risk propagation that depends on inventory policies adopted at the nodes of a supply network [13].

In contrast, risk evaluation associated with prospective supply-chain collaborations of independent companies, as those composed by the TDMS, does not have operational-level details at its disposal. For settings like this, literature offers risk evaluation approaches that adopt the perspective of the social network analysis, by focusing on the relationships assumed to exist between the network members and thus defining the network structure [10]. A probabilistic approach with different kinds of interdependent risks and disruption propagation is proposed in [10]. An approach based on the concept of Conditional Value at Risk and such network characteristics as network density, node centrality, connectivity and network size is offered in [12]. However, the approaches in [10, 12] are better suited for the settings in which the nodes at the same stage of a supply network can cover for each other in case of a disruption, as in a distribution network. In [11], a study is conducted in the context of an automotive assembly network, which better matches the network structure of supply-chain collaborations targeted by the TDMS. For these reasons, we adopt the framework presented in [11] to implement risk evaluation for prospective consortia in the TDMS, as explained below.

3. Risk evaluation

The risk evaluation framework presented in [11] refers to several complementary metrics of centrality in a network: eigenvector, authority, hub, closeness, and betweenness centrality, which have been employed for evaluating different dimensions of risk in the context of Honda's supply network [11]. Of these metrics, we adopt the former three, as explained below. First, the eigenvector centrality measure can be used to determine the risk exposure of a node in the network due to the disruption risk of its immediate partners; to this end, [11] employ Katz centrality measure as a variant of eigenvector centrality:

$$C_{K_i} = \alpha \sum_j A_{ij} C_{K_j} + \beta_i, \quad (1)$$

where C_{K_i} is the Katz centrality of node i, α is a positive constant such that $\alpha < \kappa_1^{-1}$, κ_1 is the largest eigenvalue of A — the adjacency matrix of the supply network, and β_i can be used to represent the intrinsic risk associated with node i. We follow [11] in using the World Risk Index for this purpose, which captures geopolitical risks for 181 countries, as of this writing. When implementing this risk measure in the TDMS, we save the current values of the index in the ontology on the country basis and retrieve them from the ontology when evaluating a prospective consortium based on the location of its members. In the future, the parameter β_i can be used to combine the country-based World Risk Index with the historical data on the frequency and severity of operational disruptions at a particular company or facility during past collaborations.

Further, the hub and authority centrality can be used for assessing the spread of disruptions along directed links, as in the case of material flow [11]:

$$C_{H_i} = \beta \sum_j A_{ij} C_{A_j}, \quad (2)$$

$$C_{A_i} = \alpha \sum_j A_{ij} C_{H_j}, \quad (3)$$

where C_{H_i} and C_{A_i} are the hub and authority centrality of node i and α and β are positive constants. Nodes in a supply network having a large value of hub (authority) centrality can be interpreted as companies with many customers (suppliers), direct or indirect [11]. We follow [11] by using a weighted version of (2) and (3), in which A_{ij} is being replaced with the geographic distance d_{ij} between nodes i and j, where a bigger distance represents a bigger risk of disruption of the material flow from j to i. As a result, companies having a large value of hub (authority) centrality can be interpreted as those having high transportation risk relationships with customers (suppliers) [11]. When implementing these risk measures in the TDMS, we save geographic coordinates of the companies' manufacturing locations in the ontology. Location coordinates can be requested from existing online services, such as Google Maps that offers a limited number of requests per day for free [18]. An alternative to this is the OpenWeatherMap API, which is less restrictive in terms of the number of free requests (https://openweathermap.org/price), and which we therefore employ in the implementation. When a prospective consortium is being evaluated towards the risk, the geographic coordinates of its members are being retrieved from the ontology, and the distance between every two adjacent nodes in the consortium's network is being calculated as the geodesic distance by means of the function `gdist()` from the R package `Imap` [18, 19].

4. Conclusion

TDMS is a service that underpins formation of supply-chain collaborations on the DIGICOR platform, and which can also be used as a standalone service. It allows the user to build potential supply-chain collaborations on demand, which it accomplishes via decomposition of CfT requirements and matching these with the capabilities of registered companies. The user may run the TDMS in the automated or semi-automated mode, where the latter allows the user to build the consortium incrementally. Other functionalities include replacement of consortium members and checking the consortium for gaps and redundancies. Furthermore, consortia are being evaluated in terms of fit — based on criteria that include companies' capabilities and geographic locations, as well as in terms of risk — based on the vulnerability of the consortium members to disruptions, and interrelationships between them. The advantage of the presented risk evaluation approach is that it does not require knowledge of operational-level variables, as these may be unavailable [10], and that risk indicators can be tracked at the level of individual companies. At the same time, lack of operational-level variables in the risk evaluation represents a limitation of the approach, and the risk scores thus produced should be considered crude estimates. Work is currently being done on a pilot deployment of the TDMS as a standalone service in a Welsh automotive cluster, as a continuation of the DIGICOR project [7]. Apart from that, DIGICOR is currently being integrated into the European Connected Factory Platform for Agile Manufacturing (EFPF) [20]. Future work shall address aggregation of measures (1)–(3) to a composite indicator and introduction of additional measures of risk to the TDMS.

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