A Framework to Enhance Supplier Search in Dynamic Manufacturing Networks

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Abstract — **Supplier search can be daunting for manufacturers, given the vast number of suppliers available and the work required to filter through all the information. However, even if this process allows the selection of a few potential suppliers of interest, dealing with potential suppliers for the first time may bring uneasiness, as there is no guarantee that they will comply with the requested products or services. On the other hand, suppliers which want to be seen and differentiate themselves in order to win more customers also face similar challenges. The vast amount of competitors can make it extremely difficult for any given supplier to stand out from amongst its competitors. Also, new entrants into the market with little or no reputation may find it difficult to attract their first customers. The IMAGINE project is developing a methodology and a software platform for the management of the dynamic manufacturing networks which provides innovative Supplier Search capabilities. The present paper provides an overview of the developments behind the IMAGINE platform and proposes a framework in order to help the challenges that suppliers and manufacturers face.**

I. INTRODUCTION

The process of seeking new suppliers can take place in a variety of scenarios, from individual companies seeking a specific supplier for parts and/or services, to manufacturers seeking to establish manufacturing networks, which can aggregate several different suppliers.

In either case, companies usually prefer to do business with suppliers with whom they may already have worked together previously, as the cost of choosing the wrong supplier can be very high. As an example, the cost of dealing with supplier problems costs small-business in the United Kingdom around £10 billion every year [1]. In many instances "actual supplier relationships represent one of the most important assets the company can make use of. [2]"

However, there are instances when companies must take a chance during their supplier choice process. A new part or a production process may only be available from new suppliers. In other instances, a trusted supplier may go out of business or may face an unforeseen event (e.g. natural catastrophe, plant fire, transportation delays, etc. [3], [4]) requiring a company/manufacturer to seek a new one to replace it. According to a worldwide survey of more than 500 companies, 75% have experience supply chain disruption problems, causing annual losses of €1 million for 15% of respondents and 9% lost over €1 million in a single supply disruption event [5].

The search process for new suppliers is usually performed by searching for potential suppliers in online supplier directories (i.e.: Alibaba.com, Thomasnet.com), contacting potential suppliers directly, either remotely or face-to-face, attending trade show events, seeking for information in sector-related publications, etc. All of the above activities can be quite time-consuming, as there can be hundreds of potential suppliers, and researching all the available information can soon become unmanageable. Additionally, most supplier information available still does not provide full assurance with regards to the supplier's reliability and capability to deliver the promised products or services on time. At most, suppliers can try to reassure potential customers through quality certifications which are insufficient to deal with the aforementioned issues.

On the other side of the supplier search process, suppliers face the challenge of having to distinguish themselves from their competitors, in order to attract potential customers. The process of building and maintaining business reputation takes time and well-performing suppliers, if they are still unknown, do not have many tools to assert themselves in the marketplace.

There is therefore a need for mechanisms which can provide further details and insights into the capabilities and reliability of potential suppliers, thus providing further assurance to manufacturers seeking new suppliers and allowing new suppliers with the means to provide assurance to potential customers on their good performance. This paper aims to propose a framework which can assist in solving the aforementioned issues. It first provides an overview of Dynamic Manufacturing Networks and the role of the IMAGINE project. Next, it introduces concepts related to Web 2.0, Web 3.0, such as Linked Data and the Internet of Things. Once this conceptual foundation has been laid, it then proceeds to present the suggested framework, followed by its process flowchart and architecture. Lastly, it provides a description on how the proposed framework will be validated within the context of the Furniture Living Lab of the IMAGINE project.

II. DYNAMIC MANUFACTURING NETWORKS

The globalization trends of the last decades have changed the boundaries of modern manufacturing enterprises, as manufacturers moved many of their operations across various suppliers, thus forming manufacturing networks. Such networks, also known as value networks, can be described "as networks of facilities, possibly owned by different organizations, where time, place or shape utility is added to a good in various stages such that the value for the ultimate customer is increased. [6]" Manufacturers and

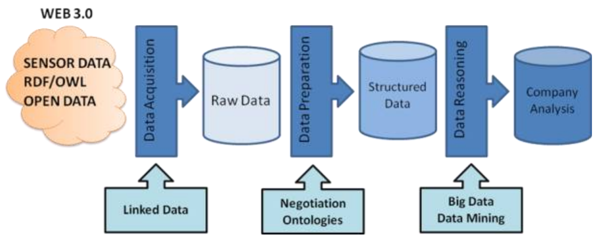

Figure 1. Proposed Framework for Semantic Company Analysis

organizations which participate in manufacturing networks choose to focus on their core competencies and mission critical operations, while outsourcing other less relevant operations to suppliers [7].

Lately, the manufacturing network concept has evolved into the Virtual Manufacturing Network (VMN), which is a manufacturing network usually built with the use of ICT for bringing together different suppliers and alliance partners creating in such a way a virtual network that is able to operate as a solely owned supply network. A special case of a VMN is the Dynamic Manufacturing Network (DMN), which is "a coalition, either permanent or temporal, comprising production systems of geographically dispersed Small and Medium Enterprises (SMEs) and/or Original Equipment Manufacturers (OEMs) that collaborate in a shared value-chain to conduct joint manufacturing. [7]" The DMN brings plenty of advantages, when compared with the more traditional concepts. Based on a view of information from various manufacturing sources and systems, DMNs enable a service-enhanced product and production lifecycle, providing companies the capability to self adapt the production to the most appropriate suppliers. In addition, the concept envisages that if during the production phase there is a supplier or a manufacturer failure the network is flexible enough to enable dynamic replacements of certain partners and therefore maintain the production scheduling [8].

A. IMAGINE Partner Search for Dynamic Manufacturing Networks

IMAGINE is a EU-funded R&D project which seeks to address the need of modern manufacturing enterprises for a novel end-to-end management of Dynamic Manufacturing Networks. With this objective in mind, the project consortium has been working on the development of "a multi-party collaboration platform for innovative, responsive manufacturing that encompasses globally distributed partners, suppliers & production facilities (SMEs and/or OEMs) that jointly conduct multi-party manufacturing" , as well as, on a "a novel comprehensive methodology for the management of dynamic manufacturing networks that provides consolidated and coordinated view of information from various manufacturing sources and systems. [9]"

One of the essential features of the proposed platform is to serve as a hub for suppliers, where they can register themselves and provide relevant information about their skills and production capabilities. Based on this information, the IMAGINE platform provides a "Partner Search" component, implemented through a collaboration portal, which allows a manufacturer to seek potential suppliers for a manufacturing network. The search component allows the filtering of potential suppliers based on several criteria, such as, production capacity, production skills, number of employees, quality certifications, production cost, estimated delivery time, amongst other factors. It also assists in finding a set of potential suppliers following a three-step process: (1) first, it begins by creating a Long List of potential suppliers based on criteria such as number of employees, turnover, location, company category and production category; (2) after this initial filtering process is performed, an additional filtering process takes place, as potential suppliers are sorted based on the dynamic criteria such as capacity rate, duration, fixed cost and variable cost, thus creating a Short List of potential suppliers for the manufacturing network.; (3) finally, the platform provides simulation capabilities, through the "DMN Evaluation" component, which simulates possible manufacturing network configurations based on the suppliers choice defined in the Short List.

The envisioned capabilities provided by the "Partner Search" component are a major leap forward in facilitating the supplier search process, as the component not only assists in filtering irrelevant suppliers, but it also provides search and simulation capabilities which were previously unavailable which give added assurance in the final selection of potential suppliers.

B. Web 2.0, Web 3.0 and the Internet of Things

The World Wide Web has been in constant evolution since its inception. The Web 1.0 of static web pages evolved into the Web 2.0, where users provided and shared their own content through social media, blogs, podcasts, etc., "through an "architecture of participation" and going beyond the page metaphor of Web 1.0 to deliver rich user experiences. [10]" In addition to user participation, the Web 2.0 has evolved into richer internet applications which can deliver desktop functionalities via a web browser (i.e. Google docs, etc.), among other functionalities.

The Web 3.0 concept is the evolution of the Web 2.0. Although visions of what the Web 3.0 may vary, one of the existing visions revolves around the Semantic Web and the generation of information by computers, in lieu of human-generated information [11]. The Semantic Web is thus "is not a separate Web but an extension of the current one, in which information is given well-defined meaning, better enabling computers and people to work in cooperation. [12]"

While the "Semantic Web is a vision of creating a Web of Data, Linked Data is a concrete means to achieve (a lightweight version of) that vision. [13]" To put it simply, whereas the Semantic Web represents a conceptual vision, Linked Data aims to be its practical and working implementation. The way in which Linked Data implements the vision of the Semantic Web is based on the following 'Linked Data principles' [14]:1. Use URIs as names for things; 2. Use HTTP URIs so that people can look up those names: 3. When someone looks up a URI, provide useful information, using the standards such as RDF* and SPARQL; 4. Include links to other URIs so that they can discover more things.

By utilizing the above four principles, the vision of building a Web of Data can begin its fulfillment, as thus mirroring for data, what website links do for the web. As each website links to other websites, a Linked Data source

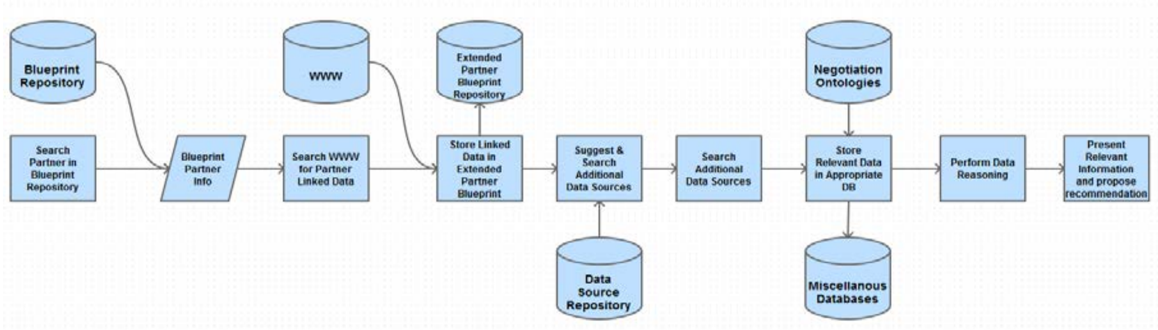

Figure 2. Proposed Semantic Company Analysis Flowchart

is linked to another Linked Data source, thus allowing for the discovery and aggregation of various data sources.

In addition to the principles of Linked Data to facilitate communication between machines, the Internet of Things (IoT) is another concept which also revolves around the issue of Machine-to-Machine communication (M2M), as "it brings us into a new era in which everything from tires to toothbrushes can be identified and connected and things can exchange information and make decisions by themselves. The communication forms will be human-human, human-thing, thing-thing. Things will be the main traffic makers. [15]"

The aforementioned concepts of Semantic Web, Linked Data and Internet of Things can be relevant towards the improvement of Supplier Search mechanisms. The way these concepts and their associated technologies may be helpful is discussed in further detail in section III.

C. Suggested Improvements to the IMAGINE Partner Search

The aforementioned capabilities provided by the IMAGINE platform assist in solving some of the current challenges in supplier search. The search capabilities of the IMAGINE platform greatly reduce the time required to find a set of suitable suppliers according to the needs and criteria of the manufacturer. However, some challenges still remain namely those related to the trustworthiness and reliability of potential suppliers, as most supplier search sites do not provide any sort of information which can help assess whether any particular supplier will deliver its services or products on time and as specified. There is therefore the need for additional mechanisms which can fulfill this gap in supplier evaluation, by providing additional information and insights which can assist manufacturers in choosing the best possible suppliers.

The monitoring of production activities is sensitive information which most suppliers are only willing to provide after they are part of a manufacturing network. If production problems with any particular supplier arise, the monitoring components of the IMAGINE platform quickly warn the manufacturer and suggest possible alternatives to the issue at hand. However, well-performing companies who produce and deliver their products on time and according to specified requirements may gain from publicly sharing some of their production data. In particular, new suppliers in a particular market may wish to have greater transparency about their production capabilities in order to provide assurance to potential customers.

Therefore, an improvement to the "Partner Search" component of the IMAGINE platform, as well as, applicable supplier search tools and sites should be the inclusion of relevant production data, obtained from production monitoring tools, which can help manufacturers and other interested parties in their supplier search process. The inclusion of such data would give an additional guarantee regarding potential suppliers that indeed their production capabilities are in line with the production requirements. Additionally, the inclusion of historical data could add further insights into the reliability of a potential supplier.

Another source of information could be in the form of user feedback, similar to what already takes place in many consumer websites and auction websites. After a the successful deployment and execution of a manufacturing network, manufacturers involved in sub-contracting work to suppliers could use the search platform to leave feedback on their experience regarding the suppliers sourced in the manufacturing network. Although this sort of mechanism is not without its drawbacks, if properly supervised to ensure that only legitimate and honest feedback is provided, then it could help other potential users in their future decision-making process regarding their supplier choices.

III. Framework for Semantic Company Analysis

A. Framework Overview

The aforementioned suggestions on how to further improve existing supplier search functions in the IMAGINE platform are based on utilizing information which is available within the manufacturing network, assuming that potential suppliers are willing to share partial production data and that manufacturing network partners are willing to provide proper feedback on their supplier choices.

However, there are other sources of potentially helpful information which may also assist in the supplier search process. The advent of Social Media and IoT brought with it a new whole variety of data sources, which can possibly enable a more in-depth and accurate context-analysis for any potential supplier. Some of the possibilities include, but are not limited to: 1.Analysis of Social Media to track online reputation of a supplier and its competitors; 2. Analysis of Search analytics regarding a potential supplier; 3. Access to wide variety of open data sources, statistical data, etc.; 4. Ability to use web crawlers to extract more specific information and data from other websites; 5. Access to real-time data from sensor networks, IoT data, etc.

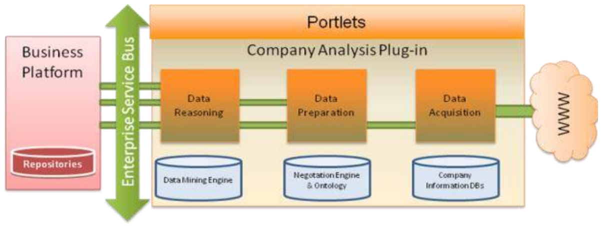

Figure 3. Proposed Architecture for the Company Analysis Plug-in

While the new data sources provided by the new digital age are relevant by themselves, if combined with other types of data, they can provide further insights which otherwise would not be available, if only traditional data sources were to be utilized. Hence, there is a need for an appropriate a framework and a methodology on how to integrate these additional sources of data and information in the supplier search process. A possible framework which can be utilized to perform analysis on companies is shown in Figure 1.

Firstly, the framework shall take into account a wide variety of data sources, including but not limited to, Linked Data, Sensor Data, XBRL data, as well as, the more common data formats which can be found on the web (text, RSS feeds, spreadsheets, documents, etc.). As illustrated in Figure 1 above, Linked Data principles can be applied during the data acquisition phase in order to help solve possible Data Interoperability issues which may arise [16]. Linked Data will also assist in the data retrieval process, by allowing the discovery of data which could be of interest towards the company evaluation process, such as, information about alternative suppliers, possible competitors and data related to the context in which the potential suppliers operate. Additionally, Linked Data can be explored in offering innovative data visualizations, such as browsing through potential suppliers in a more interactive way. With regards to Sensor data, the framework would like to propose and encourage enterprises to publish relevant Iot-related data related to their manufacturing and logistics supply chains. The push towards greater transparency is beneficial for both data consumers and providers:

• IoT Data providers – Reliable and dependable manufacturers and suppliers can gain an advantage of their competitors by publishing IoT-related data which can demonstrate their commitment and production efficiency, as the data will provide evidence to potential customers and thus assisting in generating future business

• IoT Data consumers – The availability of IoT-related data regarding a potential supplier can provide data consumers with greater insight and greater confidence whenever choosing a potential supplier.

Once data has been gathered, in the "Data Preparation" phase, negotiation mechanisms can assist in the development of reference ontologies and in the structuring of the data collected. Negotiation mechanisms can assist in performing semantic negotiation of the various concepts described by the data acquired (e.g. [17]). The variety of data sources can lead to semantic mismatches which must be solved in order to structure the data acquired, while ontologies can assist in the storage of relevant relationships between data and data sources, as well as, in the permanent storage of relevant static data [18], [19]. After the data acquired has been organized and is structured into a processable form, it is then ready to be analyzed. In this phase, data mining algorithms may be employed, however, whenever applicable, Big Data methodologies may also be applied (i.e.: large data streams from sensor networks, etc.). It is expected that once the data has been analyzed, that company analysts will be able to perform a proper company evaluation which suits their needs.

B. Semantic Company Analysis Flowchart

The process of performing a Semantic Company Analysis, based on the proposed framework, is illustrated in Figure 2.

It begins by searching the Blueprint Repository provided by the IMAGINE platform for existing information regarding a potential supplier [8], [20]. The IMAGINE platform and associate methodology provide Partner Blueprints as a mechanism whereby companies provide information about themselves, such as contact information, number of employees, annual turnover, skills and capabilities. Therefore, it makes sense to first retrieve the information that is already available in the Partner Blueprints before seeking for additional information in other sources. If already available, historic information regarding the partner's performance in previous networks, should also be made available.

Once the information from the Partner Blueprints is retrieved, it is then possible to confirm basic information about the company under analysis (e.g. name, location, etc.) and then proceed to search the WWW for additional information,

The first search for additional information will be performed by approaching sources of data and information which are based on Linked Data principles. The usage of Linked Data will assist in uncovering additional facts and/or sources of data.

The results from the Linked Data search process will return additional data and information which must then be confirmed by the user, to ensure that indeed the results are relevant for the analysis at hand. The results which are deemed relevant are then stored in a different repository, the "Extended Partner Blueprint Repository", as an extension to the IMAGINE Blueprint Repository.

Based on the information retrieved from the Partner Blueprint in IMAGINE, as well as, the information retrieved from Linked Data sources, the framework should then suggest additional data sources to continue the data acquisition step. Additional sources of data could include, for example, statistical data regarding the region where the company under analysis operates, social media data, Google Analytics data, weather data, etc. The framework should have a separate repository for data sources and their possible applications, as certain data sources may only have relevance according to certain criteria regarding the company being analyzed (e.g.: application of UK statistical data for UK-based companies, industry-related sites according to the sector in which a company operates, etc.).

Once additional information is retrieved, there is the need for the user to confirm which information is relevant, as previously done with Linked Data search results. As the relevant data may come in a wide variety of formats, it is foreseen that additional databases may necessary to story relevant search results according to their type.

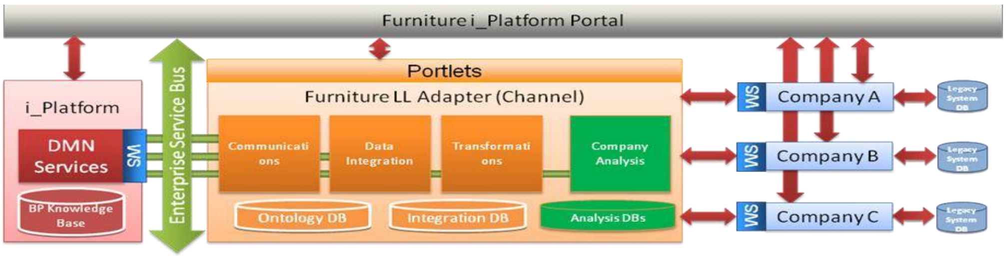

Figure 4. Proposed Integration of the Semantic Company Analysis component in the Furniture Living Lab Adapter [21]

After the previous data acquisition data steps, it is then possible to perform data reasoning using appropriate data mining tools and algorithms, and then present the most relevant data and information, as well as, recommendations regarding the company under analysis.

C. Proposed Framework Architecture

In order to implement the proposed framework, a software architecture is suggested in Figure 3.

The proposed Company Analysis Adapter is meant to be modular in nature, so that it may be integrated and suited to different applications, as mentioned in the previous section.

The Adapter is constituted by the following major components: 1. Data Acquisition – This component is to be implemented through a Database Engine such as Openlink Virtuoso or similar tool, which allows the aggregation of data from various data sources, including Linked Data, web data, among others; 2. Data preparation – The Data Preparation component will be comprised of a negotiation rules engine, assisted by an ontology, which will be responsible for evaluation of the data acquired and whether it should be preserved for analysis or discarded; 3. Data Reasoning – The Data Reasoning component of the adapter is to be implemented by adapting an open-source data mining tool such as R or RapidMiner. Appropriate tools for data mining of large sets of data, if necessary, will employ appropriate open-source "Big Data" tools; 4.Company Information Databases – The Adapter will require the use of additional data repositories, including graph-based and relational databases, according to the data to be stored and analyzed; 5. Portlets – The User Interface of the component will be implemented via the use of Portlets, which can then later be integrated into a platform portal.

IV. FURNITURE LIVING LAB IN IMAGINE

A. Framework Validation within the Context of the Furniture Living Lab

The Furniture Living Lab has been defined to demonstrate the interactions between the IMAGINE Platform and Legacy Systems through Web Services and Adapters developed ad-hoc. The objective is to pilot an end-to-end management of a DMN created on the basis of an arising business opportunity. This LL is focused on furniture manufacturing processes covering the cycle time from the detection of new business opportunities to the delivery of the produced goods.

The definition of this LL is mainly based on the furniture scenario proposed for the IMAGINE project, which proposes a production environment composed in order to service one special order. This was developed to demonstrate how some production problems can be identified and solved. It is also based on open standards in order to ensure a given level of interoperability, flexibility and security. The order meets some conditions to be considered special and to be managed through a DMN in the IMAGINE platform: custom configuration, high volume and tight delivery terms. The objective is the use of the platform in conjunction with the ERP legacy system in order to deal with the special order.

As mentioned previously, the IMAGINE platform provides capabilities to search for new suppliers and simulate the current production processes inside the DMN. This simulation allows a better selection of production partners in order to build a more efficient production network. The platform also provides a system to communicate and exchange data inside the platform with punctual human interaction. The objective is to be able to connect the platform to any ERP system by using Adapters. This allows companies to react to production issues faster and more effectively.

On the other hand, the proposed LL introduces a new approach that it is not very extended in the furniture sector: the collaborative manufacturing approach. Although the proposed Furniture LL is defined initially for companies which are currently managing a small production network in some way, the availability of the IMAGINE platform and its functionality fosters the adoption of this production approach by companies which are not following this at this moment. This new approach is also being in more demand and it facilitates new business opportunity for many SMEs.

B. Company Analysis Integration in the context of the Furniture Living Lab

The Furniture Living Lab has developed an adapter which facilitates the registration of Furniture Manufacturers in the IMAGINE platform. The adapter, through the use of Web Services, provides mechanisms for easy upload of Partner and Product information.

Given the modular nature of the Company Analysis adapter, the Company Analysis adapter and its supporting databases may be integrated within the existing Furniture Living Lab adapter, as shown in Figure 4, thus providing additional functionalities to the adapter. The use of Portlets as an interface for the Company Analysis adapter does not disrupt in any way the other functionalities of the adapter, serving thus as a complement to them.

In order to ease the communication between the adapter and the legacy systems, a web services application has been also developed. This application offers a set of services according to the IMAGINE blueprints data model to retrieve specific information from the ERP of the companies. Currently, the application implements a set of web services to retrieve values from GdP (a specific ERP for the furniture industry supported by AIDIMA) and funStep (ISO 10303-236) [22]. To ease the integration, the architecture of the application offers an additional empty class which can be used to implement the specific queries to retrieve values from any other ERP database. This way, the ERP system and the updates in the implementation of the data retrieval are transparent to the Adapters and the IMAGINE platform.

In the particular context of the Furniture Living Lab's needs, the proposed framework could provide additional features, such as the ability to search and aggregate publicly available information on a given company and the ability to view, upload and edit feedback information on potential suppliers. Also, potential suppliers could be given the possibility of sharing certain production monitoring data as proof of their reliability and production capabilities, allowing the framework to provide recommendations based on the information gathered

V. CONCLUSIONS AND FUTURE WORK

The proposed framework and the associated software architecture aim to provide an innovative approach towards solving some of the major challenges that manufacturers face when searching for potential suppliers. The integration of relevant manufacturing data into supplier's profiles, as well as, the provision of feedback mechanisms and the integration of additional data sources can provide additional insights into a supplier's capabilities and reputation.

Future work, as part of the first author's PhD thesis [CA8], will include research into most appropriate technologies for the implementation of the proposed software architecture, as well as, its deployment. Future improvements to the framework may include the addition of Machine Learning algorithms to assist in the analysis and recommendation process.

ACKNOWLEDGMENT

The authors wish to acknowledge the European Commission for their support in funding this work through Projects IMAGINE: Innovative End-to-end Management of Dynamic Manufacturing Networks (No. 285132), and FITMAN - Future Internet Technologies for MANufacturing industries (No. 604674).

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