Digital Innovation Hubs: Two-mode and Network-Based View on Technology and Services Provided

Anna Ujwary-Gil[1] and Bianka Godlewska-Dzioboń[2]
[1]Institute of Economics, Polish Academy of Sciences, Poland
[1]Network Analysis Laboratory, Cognitione Foundation, Poland
[2]Cracow University of Economics, Poland
ujwary@inepan.waw.pl
godlewsb@uek.krakow.pl

Abstract: The Digital Innovation Hub (DIH) is a relatively young research area emerging on the basis of well-known ideas of technology parks or clusters. DIH is mainly focused on the digital transformation of enterprises and the development of a given region in the context of Industry 4.0 based on digital technology. The European Union is the initiator of the "Digital Europe" program for 2021-2027, aiming to promote the transfer of digital specialist knowledge to economic entities. The authors chose the DIHs operating in Poland as a starting point for network analysis in the context of the technology and services provided by Polish DIHs. This research aims to measure network cohesion, the centrality of individual DIH, and its specialty (exclusivity). It is based on secondary data collected using the Smart Specialization Platform based on which the two two-mode networks have been developed: actor x technology (ATij) and actor x services provided (ASPij). Measurements and visualization were made using two network programs (UCINET and ORA PRO). The following social network analysis techniques were used: 1) Two-mode cohesion: density, diameter, and fragmentation; 2) Two-mode centrality: degree and betweenness, and 3) Two-mode specialty (exclusivity). The results show two-mode networks consisting of the following nodes: 15 actors (A) or DIHs; 29 technologies (T), and 16 services provided (SP) forming a meta-network. They provide an insight into the network structure, most influential actors (DIHs), technologies, and services, as well as the specialty of each DIH in the European country, thus giving rise to further comparative research, using secondary data for the other 26 countries of the European Union.

Keywords: digital innovation hub, DIH, two-mode network, centrality, cohesion, digital knowledge, technological knowledge, social network analysis, specialty, row exclusivity

1. Introduction

The Digital Innovation Hub (DIH) is a relatively new area of research and a concept of the European Commission. They first appeared as Competence Centers, which were to produce a specific technology to support digital transformation in Europe. Then, the DIH concept was developed. Apart from the production of specific products, it is designed to build an ecosystem of digital innovation by uniting different environments and sectors, exchanging knowledge, experiences, and technologies (Hervas-Oliver et al., 2021). The idea of establishing DIHs appeared for the first time in the European Commission communication entitled "Digitising European industry: Reaping the full benefits of a digital single market (COM, 2016). The Commission then committed € 500 million from the Horizon 2020 budget to creating the European DIH network. As part of the recruitment, applications from leading competence centers were accepted. Together with their partners, they created hubs specialized in the subject of announced competitions, such as digital innovations in production processes, photonics, robotics, or advanced data processing. Currently, there are over a dozen Polish hubs on the list of the European Commission. The first publications on DIHs indexed in Web of Science or Scopus appeared only in 2018.

European Union dedicated programs, incl. digital competences or Digital Europe (financial perspective for 2021-2027) made the digital transformation of enterprises towards Industry 4.0 a reality (Florek-Paszkowska et al., 2021; Ujwary-Gil et al., 2022). The program focuses on several priorities: 1) building and strengthening EU capabilities in the field of High-Performance Computing; 2) research and development of artificial intelligence; 3) strengthening cybersecurity due to its importance for European democracy and the EU economy; 4) developing digital competences so that the knowledge and skills to use the latest digital technologies become more and more common; 5) implementing interoperable solutions in areas of public interest and facilitating entrepreneurs, especially small and medium-sized enterprises, to access digital technologies and specialist knowledge (Mărcuț, 2020).

The Digital Europe Program intends to provide DIHs with access to technological knowledge and experiments to better assess digital transformation projects' viability. The testing and experiment services provided by DIHs may also include other enabling technologies contributing to the implementation of new solutions. The DIHs network

is to cover the widest possible area of the European Union countries. Subsidies for their development will be awarded directly by the European Commission.

In Poland, in 2019, 5 winning applications were selected from among 42 applications for the ministerial competition entitled "Standardization of digital innovation hub services to support the digital transformation of enterprises" (Ministry of Entrepreneurship and Technology, 2019). The program aimed to select, expand, and supplement the potential of centers that can perform the role of DIHs, develop good practices, and standardize the services they provide to support entrepreneurs in the field of product, service, and organizational transformation using the latest technological solutions. In the future, other innovation incubators will benefit from the experience of newly established DIHs. This type of organization aims to accelerate the transformation of the economy towards Industry 4.0. The digital revolution creates opportunities for businesses large and small, but many still struggle to know what technology to invest in and how to finance their digital transformation. Small and medium-sized enterprises (SMEs) are particularly slow to implement digital technologies (Gancarczyk and Ujwary-Gil, 2021). It is estimated that only one in five enterprises in the EU is highly digitized. 60% of large enterprises and more than 90% of small ones are slow to implement digital innovations, with the latter representing more than 99% of all enterprises in Europe (Eurostat, 2021).

The idea of DIH is to support and improve the competitiveness of enterprises using digital technologies dedicated to the digital development of activities, business models, production, services, and business processes. Overall, DIHs operate as a comprehensive enterprise service offering (Vakirayi and Belle, 2020): 1) testing and experimenting with digital innovations in the areas listed; 2) intermediating between users and providers of digital innovations in the value chain; intermediation between companies and investors, providing enterprises in the region with knowledge, expertise, and technologies; 3) contacts with training providers, investors, access to financing digital transformation, strengthening innovation, a platform for cooperation for various stakeholders. Services understood in this way are to act as the so-called one-stop-shop offering companies in their region comprehensive access to the latest knowledge, experience, technology, as well as technological, construction, and measurement infrastructure. Moreover, they enable the testing and implementation of digital innovations for the created products, processes, and business models (Ujwary-Gil and Potoczek, 2020). DIH's offer is addressed to companies where the level of digital technology applications is low and whose potential currently does not allow them to meet the challenges posed by the rapid technological development based on the use of microelectronics, photonics, and digitization (Georgescu et al., 2021).

Therefore, as proposed by the European Commission, the Digital Innovation Hub is a one-stop-shop where start-ups and mid-caps (mid-capitalization) can get help in improving their business, manufacturing processes, products, and services through digital technologies. One of the key priorities of the European Industry Digitization Initiative launched in 2016 is to support a strong network of DIHs to ensure that every business in Europe can benefit from digital technologies (DEI, 2016). Its aim is to coordinate the work of digitization of industry, co-invest in the development of European digital innovation, provide an appropriate legal and regulatory framework, and strengthen the necessary skills to carry out the digital transformation.

The article aims to examine the network structure of DIHs operating in Poland from the perspective of two-mode networks: technology and services provided by DIHs in terms of two-mode cohesion, two-mode centrality, and two-mode specialty (row exclusivity). This is the first such DIHs study that looks at selected technologies and services through the prism of a network approach that assumes interdependence and relationships between actors. In this context, the actors are DIHs operating in Poland. With the above in mind, the research questions (RQ) are as follows:

RQ1: How cohesive are technology and services provided networks?
RQ2: Which digital innovation hubs, technologies, and services are centrally positioned in the networks?
RQ3: What are the DIHs' specialties in technology and services provided networks?

2. Network approach to Digital Innovation Hub

The study used social network analysis techniques to measure and visualize the structure of selected DIHs' networks operating in Poland. For this purpose, two network programs were used: UCINET (Borgatti et al., 2002) and ORA PRO (Altman et al., 2020). The network approach allows for the association of DIH data with technology and services provided (c.f., Ujwary-Gil, 2017). The secondary data of the Smart Specialization Platform (S3 Tools

and Data Sources, 2022) was used, which is very well structured (standardized for each DIH). Network data (nodes) consists of the following DIHs, i.e. actors (A), technologies (T), and services provided (SP) (Table 1).

Table 1: DIHs operating in Poland, technologies used, and services provided (sorted alphabetically)

ID	DIH name (A)	ID	Technology (T)	ID	Services provided (SP)
A01	Centre for Advanced Manufacturing Technologies, Wroclaw University of Science and Technology	T01	Additive manufacturing	SP01	Access to funding and investor readiness services
A02	CYBERSEC HUB	T02	Advanced, or high-performance computing	SP02	Awareness creation
A03	DIH4.AI	T03	Artificial intelligence	SP03	Collaborative researchs
A04	Emerging Transactional and Financial Technology Hub (ETFTH)	T04	Big data, data analytics, data handling	SP04	Commercial infrastructure
A05	HPC4Poland	T05	Cloud computing	SP05	Concept validation and prototyping
A06	Institute of Electron Technology (ITE)	T06	Communication networks	SP06	Digital maturity assessment
A07	IoT Poland Foundation Hub	T07	Cyber-physical systems	SP07	Ecosystem building, scouting, brokerage, networking
A08	IT and Expert Hub Supporting Biomedical Research, Technology and Education (BioMedHub)	T08	Cyber security	SP08	Education and skills development
A09	Krakow Technology Park	T09	Distributed ledger technology	SP09	Incubator/accelerator support
A10	Lublin Medicine Cluster	T10	Gamification	SP10	Market intelligence
A11	NASK National Research Institute	T11	Industrial biotechnology	SP11	Mentoring
A12	PIAP HUB	T12	Interaction technologies	SP12	Pre-competitive series production
A13	Poznan Science and Technology Park of Adam Mickiewicz University Foundation	T13	Internet of things	SP13	Testing and validation
A14	Regional Digital Innovation Hub related to Internet of Things (IoT North Poland HuB)	T14	Internet services	SP14	Visioning and strategy development for businesses
A15	Silesia Smart Systems	T15	Laser-based manufacturing	SP15	Voice of the customer, product consortia
		T16	Logistics	SP16	Other
		T17	Micro/nanoelectronics		
		T18	Mobility & location-based technologies		
		T19	Nanotechnology		
		T20	New media technologies		
		T21	Organic and large area electronics		
		T22	Photonics and imaging technologies		
		T23	Quantum computing		
		T24	Robotics		
		T25	Screens and display technologies		
		T26	Sensory systems		
		T27	Simulation, modeling, and digital twins		
		T28	Software as a service and service architectures		
		T29	Virtual, augmented, and extended reality		

Source: Based on S3 Tools and Data Sources: Digital Innovation Hubs (accessed 14 March 2022).

The nodes listed in Table 1 form the basis for analyzing the structure of the two-modal network using cohesion, centrality, and specialty (exclusivity) techniques. In the literature on the subject (e.g., Borgatti et al., 2013; Carley

and Reminga, 2004; Prell, 2012; Robins, 2015; Ujwary-Gil, 2020, 2019; Wasserman and Faust, 1994), the interested reader will find these network techniques much more widely discussed.

2.1 Two-mode cohesion

Two-mode cohesion calculates standard cohesion measures for a two-mode network like: density, diameter, and fragmentation directly on a two-mode dataset, taking into account the sizes of each mode (Borgatti and Everett, 1997). Density is the number of ties divided by n * m, where n is the number of rows and m are columns in a matrix. Diameter is the length of the longest geodesic in the two-mode network within components. Fragmentation is the proportion of vertices that cannot reach each other (Borgatti et al., 2013; Wasserman and Faust, 1994).

2.2 Two-mode centrality and row exclusivity

Two-mode centrality calculates the two-mode versions of degree and betweenness centrality. Any two-mode network can be represented as a bipartite graph and this can be submitted to the standard one-mode centrality routines. This routine normalizes the scores against the maximum possible scores in an equivalently sized connected two-mode network and provides appropriately scaled measures (Borgatti and Everett, 1997; Everett, 2016). The centrality degree of a node determines the number of direct incoming and outgoing relations, and betweenness centrality means the degree of indirect connections between nodes, allowing to determine who or what in the network is best connected with other nodes, acts as bridges (in positive and negative meaning) and is also the most central node in the entire network with potentially high impact on other nodes in the network (Borgatti and Everett, 2000; Sarkar et al., 2022).

Additionally, in this area, it is indicated which nodes are characterized by the so-called specialty or row exclusivity, which were calculated using the formulas (Carley and Reminga, 2004):

for technology specialty $\sum_{j=1}^{|T|} \mathrm{AT}(i,j) * \exp\left(1 - \mathrm{sum}\left(\mathrm{AT}(:,j)\right)\right)$

for services provided specialty $\sum_{j=1}^{|SP|} \mathrm{ASP}(i,j) * \exp\left(1 - \mathrm{sum}\left(\mathrm{ASP}(:,j)\right)\right)$

where:

|T| – number of elements in set T (technology)
|SP| – number of elements in set SP (service provided)
A – DIH's name, actor (A)
AT(i,j) – actor *i* uses technology *j*
ASP(i,j) – actor *i* provides service *j*

3. Results and data analysis

Based on the nodes in Table 1, two-modal networks were created: actor x technology (AT_{ij}) and actor x services provided (SP_{ij}), which are illustrated in Figures 1 and 2. Affiliation networks indicate which technologies and services are provided by a given DIH. The density is 0.315 (137 links) in the technology network, which means that the DIHs offer slightly over 30% of technologies in Poland. In the case of the services provided network, the density is 0.517 (124 links), i.e. almost 52% of services are offered by Polish DIHs of all possible (see Table 1 and Figure 1, 2). The diameter for both networks is 4.000. The longest distance between 2 technologies and services in the network is 4 (4 pairs of nodes had this geodetic distance). The larger the diameter, the less tightly connected the nets. The fragmentation for the technology network is 0.217, and for the service network, it is 0.065. It means that the percentage of nodes in the technology network that are disconnected from actors is 22%, and in the services provided network – 6.5%. There is a particular risk of not linking actors with technology and services. However, it is impossible to estimate this risk's acceptable/unacceptable level due to the lack of comparable studies.

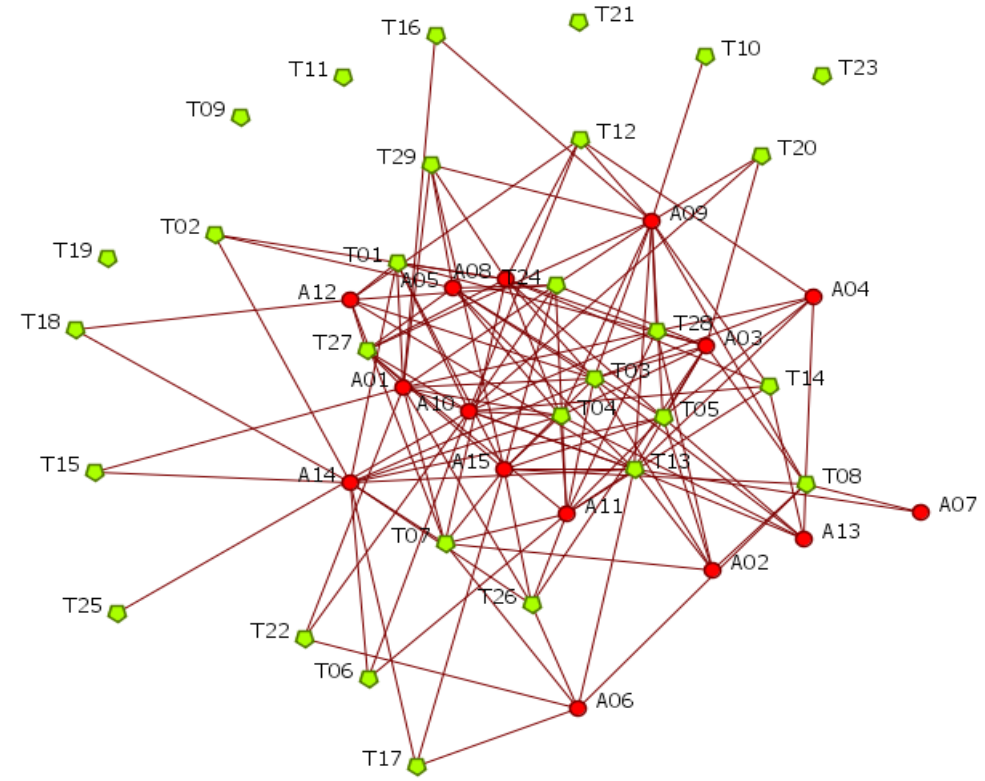


Figure 1: Visualization of an affiliation network: actor x technology

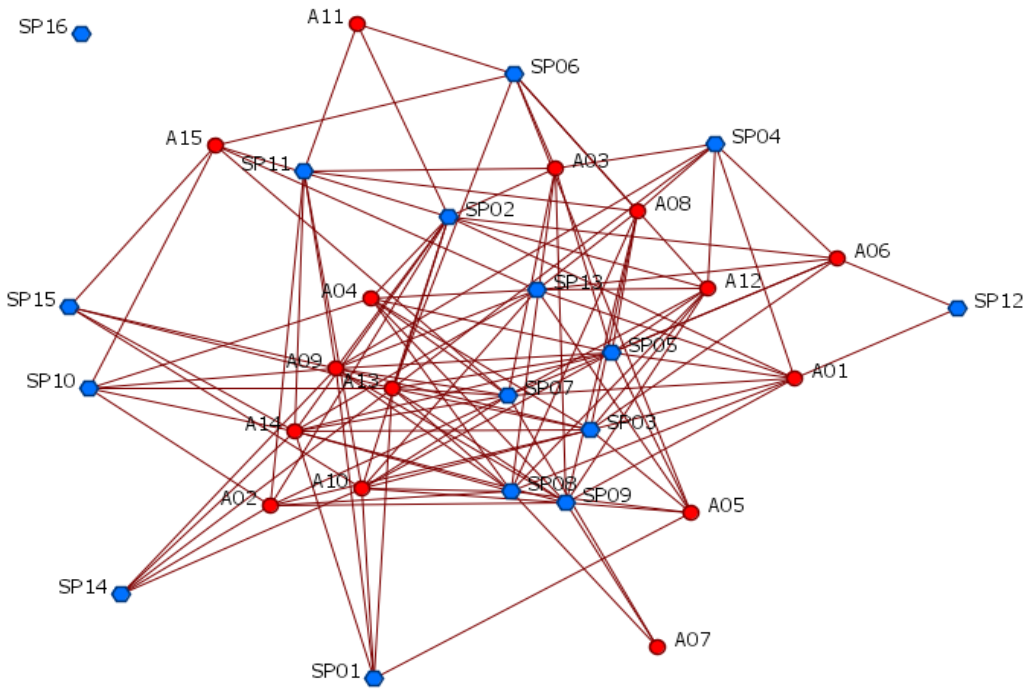


Figure 2: Visualization of an affiliation network: actor x services provided

Table 2 shows the normalized results for two-mode centrality: degree and betweenness for the network technology and services provided. The thing about two-modal centrality is that they show the results for each mode. For the technology network, the most central technologies (in the sense of incoming and outcoming connections) are artificial intelligence - T03 (0.800), big data, data analytics, data handling - T04 (0.667), cloud computing - T05 (0.677), and internet of things - T13 (0.933). On the other hand, betweenness centrality, a connecting node that is best connected with other nodes, with a potentially high impact on other nodes in the

network, is again artificial intelligence - T03 (0.052) and the internet of things - T13 (0.109). Central actors (DIHs) are A01 (0.542) and A09 (0.583), as is the case of betweenness centrality. Additionally, we can include here the actors A10 (0.119) and A14 (0.110). For the services provided network, the most central services are awareness creation - SP02, ecosystem building, scouting, brokerage, networking - SP07, education and skills development - SP08, incubator/accelerator support - SP09 (0.800). The services that connect the most are access to funding and investor readiness services - SP01 (0.088) as well as ecosystem building, scouting, brokerage, networking - SP07 (0.076). In contrast, the most influential DIHs in the service network are A09 (0.867), A13, and A14 (0.800). For betweenness centrality: A01 (0.058) and A14 (0.067).

Table 2: Two-mode centralities of technology network and services provided network with actor's specialties

Technology network							**Services provided network**						
T	D	B	A	D	B	Actor's Technology Specialty	SP	D	B	A	D	B	Actor's Services Provided Specialty
T01	0.467	0.020	**A01**	0.542	0.102	T15, T16	**SP01**	0.333	0.006	**A01**	0.600	0.058	SP12
T02	0.200	0.002	**A02**	0.250	0.010	T07, T08, T28	**SP02**	0.800	0.082	**A02**	0.533	0.026	SP14
T03	0.800	0.052	**A03**	0.417	0.040	T20	**SP03**	0.733	0.046	**A03**	0.533	0.026	SP04, SP06, SP11
T04	0.667	0.040	**A04**	0.250	0.012	T12	**SP04**	0.467	0.017	**A04**	0.533	0.019	SP10
T05	0.677	0.034	**A05**	0.333	0.025	T02	**SP05**	0.733	0.045	**A05**	0.467	0.019	SP01
T06	0.200	0.004	**A06**	0.250	0.022	T17, T22	**SP06**	0.467	0.029	**A06**	0.467	0.037	SP12
T07	0.533	0.025	**A07**	0.083	0.001	T08	**SP07**	0.800	0.071	**A07**	0.200	0.001	SP07, SP08, SP09
T08	0.533	0.028	**A08**	0.458	0.052	T02	**SP08**	0.800	0.061	**A08**	0.533	0.026	SP04, SP06, SP11
T09	0	0	**A09**	0.583	0.141	T10	**SP09**	0.800	0.061	**A09**	0.867	0.082	SP01, SP14, SP15
T10	0.067	0.000	**A10**	0.500	0.119	T25	**SP10**	0.400	0.011	**A10**	0.733	0.054	SP01, SP14, SP15
T11	0	0	**A11**	0.458	0.047	T06	**SP11**	0.467	0.025	**A11**	0.200	0.004	SP06, SP11
T12	0.333	0.011	**A12**	0.333	0.037	T18	**SP12**	0.133	0.000	**A12**	0.600	0.028	SP04, SP06
T13	0.933	0.109	**A13**	0.250	0.011	T14	**SP13**	0.667	0.042	**A13**	0.800	0.076	SP01, SP14, SP15
T14	0.333	0.009	**A14**	0.500	0.110	T15, T18	**SP14**	0.333	0.005	**A14**	0.800	0.067	SP01, SP14, SP15
T15	0.133	0.001	**A15**	0.500	0.064	T17	**SP15**	0.333	0.007	**A15**	0.400	0.018	SP15
T16	0.133	0.001					**SP16**	0	0				
T17	0.200	0.003	**Legend:**										
T18	0.133	0.001	D (degree centrality); B (betweenness centrality); T (technology); A (actor, DIH); SP (service provided).										
T19	0	0	**Value statistics for actor node centrality (D) in actor x technology network**										
T20	0.200	0.003	Min:	0.083	Mean:	0.381	Lower quartile:	0.250					
T21	0	0	Max:	0.583	Std.dev:	0.138	Median:	0.417					
T22	0.200	0.005					Upper quartile:	0.500					
T23	0	0	**Value statistics for technology node centrality (D) in actor x technology network**										
T24	0.533	0.023	Min:	0.067	Mean:	0.381	Lower quartile:	0.200					
T25	0.067	0.000	Max:	0.933	Std.dev:	0.235	Median:	0.333					
T26	0.400	0.012					Upper quartile:	0.533					
T27	0.533	0.024	**Value statistics for actor node centrality (D) in actor x services provided network**										
T28	0.533	0.024	Min:	0.200	Mean:	0.551	Lower quartile:	0.467					
T29	0.333	0.007	Max:	0.867	Std.dev:	0.191	Median:	0.533					
							Upper quartile:	0.733					
			Value statistics for services provided node centrality (D) in actor x services provided network										
			Min:	0.133	Mean:	0.551	Lower quartile:	0.333					
			Max:	0.800	Std.dev:	0.214	Median:	0.467					
							Upper quartile:	0.800					

The so-called "specialty" results are interesting, which detect row nodes that have ties to column nodes that comparatively few other row nodes have (Altman et al., 2020; Ashworth and Carley, 2006). The specialty (row exclusivity) results indicate the actors (DIHs) from the perspective of unique technologies and services provided, which may be beneficial information for companies with which DIHs cooperate in a given specialization. When computed on an actor x technology (AT_{ij}) and actor x services provided (AS_{ij}) networks, this is called technology/services provided exclusivity and detects actors who offer technology/services that few other actors provide. Figure 3, like Figures 1 and 2, was obtained using the ORA PRO program (Altman et al., 2020).

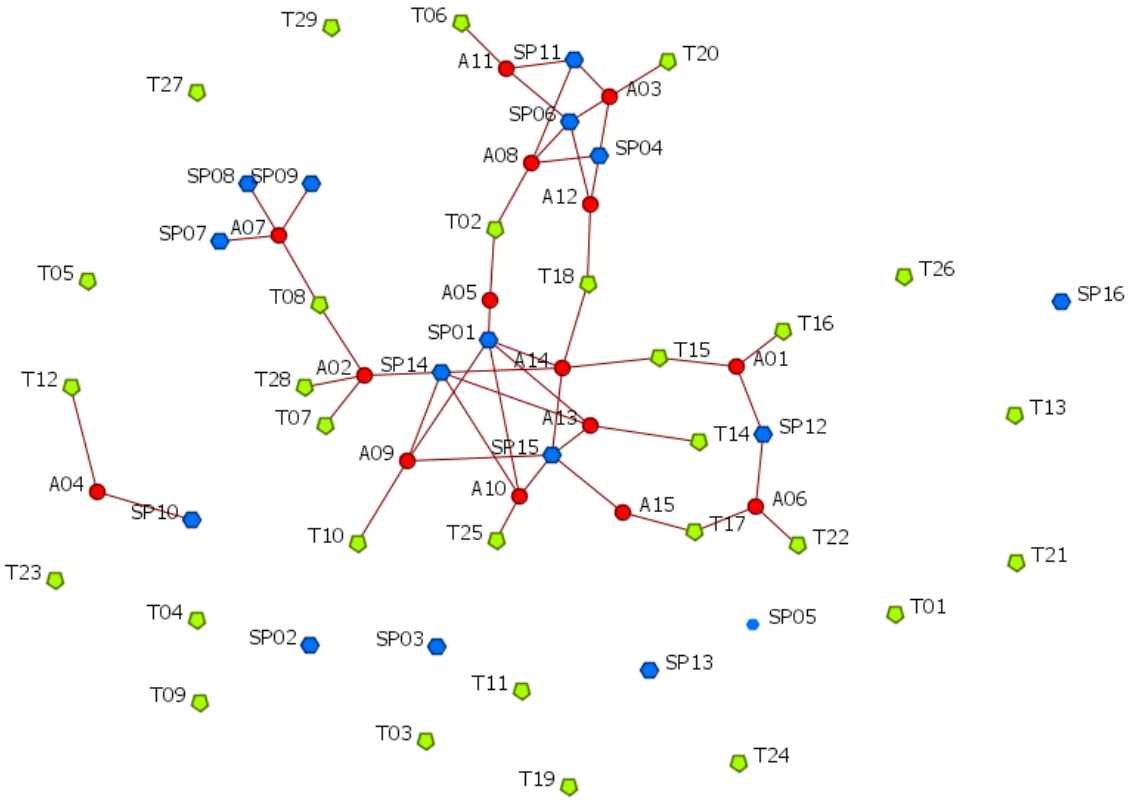


Figure 3: Visualization of actors' (DIHs) technology and services provided specialties

Figure 3 shows the links between actors and technology; and actors and services in the context of their specialty (exclusivity). It also indicates through which technologies and services a given DIH are linked to another in the region. For example, actor A01 is associated with actor A06 through SP012 (pre-competitive series production) and with actor A14 through T15 (laser-based manufacturing). In turn, actor A09 is related to actor A05 and A14 through SP01 (access to funding and investor readiness services); and with actor A02 through SP14 (testing and validation). On the other hand, with actor A13 through SP01 (access to funding and investor readiness services), SP14 (testing and validation), and SP15 (voice of the customer, product consortia). The same actors, A01 and A09, have the highest betweenness centrality (see Table 1). Such analysis can be the basis for technological or service cooperation between DIHs based on shared specializations.

4. Conclusion

The article is the first attempt to capture the digital innovation hubs of a given region from the perspective of a network of relationships and interdependencies. Wherever there is a given community of coexisting entities, the network analysis instruments are used to study the network of relations structure, as well as the position of nodes in the network and their potential impact on the remaining ones in the studied population (within the adopted network boundary). Here, the network boundary were DIHs operating in a given region, i.e. one of the European Union countries. Concerning the research questions posed in the introduction (RQ1, RQ2, RQ3), the following answers are formed:

RQ1: How cohesive are technology and services provided networks?

The topology of technology and services provided networks in terms of their density, diameter, and fragmentation indicate that the studied networks have a relatively high density of connections between actors and technologies (31.5%); actors and services (52%). The diameter of the network is 4. The longer the distance, the further the node is from other network participants, which may result in isolating it from the flow of knowledge, information, or experiences. The risk of network fragmentation (scattering) is visible in the case of the technological network (0.217) and services provided network (0.065), but there is no reference to other networks here to indicate the scale of the risk.

RQ2: Which digital innovation hubs, technologies, and services are centrally positioned in the networks?

The degree of centrality (incoming and outcoming) and betweenness centrality for each node in the networks were presented in Table. For actors in the technology network, the minimum centrality (min) value was 0.083, the maximum (max) 0.583. The mean for the entire network was 0.381, and the standard deviation (SD) was 0.138. On the other hand, for technology nodes, value statistics are slightly different, the value of min. = 0.067, max. = 0.993, mean = 0.381, and SD = 0.235. In services provided network and actors of this network, min. = 0.200, max. = 0.867, mean = 0.551, SD = 0.191; for services provided node: min. = 0.133, max. = 0.800, mean = 0.551, and SD = 0.214.

The most central technologies from the point of view of the most frequently offered by actors (DIHs) are T13 (Internet of things), T03 (Artificial intelligence), T05 (Cloud computing), T04 (Big data, data analytics, data handling). The technologies T07 (Cyber-physical system), T08 (Cyber security), T24 (Robotics), T27 (Simulation, modeling, and digital twins), and T28 (Software as a service and service) are equivalent in terms of central position in the network (0.533). architectures). The T13 (Internet of things) technology fulfills the functions of a broker or an intermediary between technologies, which may mean that many products and services are based on the use of this technology. In turn, the central actors (in terms of the number of technologies offered) are A09, A01, A10, A14, and A15. The functions of brokers, intermediaries between actors in the technology network can be assigned to actor A09, whose centrality betweenness was 0.141, and to actor A10 (0.119).

In the service network, the most central services are SP02 (Awareness creation), SP07 (Ecosystem building, scouting, brokerage, networking), A08 (Education and skills development), and A09 (Incubator/accelerator support). The service that acts as an intermediary between services in the network is SP02 (Awareness creation). In turn, the most central actors in the service network are A09, A13, A14, and acting as a broker in the service network is A09 (0.082).

The value of these studies is the indication of technological specialization and services in a given region, which may be an indication for potential investors from Poland, but also from other countries with which DIHs cooperate technologically or as part of the provision of services/products, taking into account their central role in technology network and services.

RQ3: What are the DIHs' specialties in technology and services provided?

To identify which DIHs (actors) specialize in a given technology and services provided, row exclusivity formulas (as presented in Section 2.2), also called specialty, were used. Table 2 included specific technologies and services that are unique to a given DIH, i.e. actors (A01-A15), which for technology are as follow: A01' unique technological competences are T15 (Laser-based manufacturing) and T16 (Logistics); for A02: T07 (Cyber-physical systems), T08 (Cyber security), and T28 (Software as a service and service architectures); A03: T20 (New media technologies); for A04: T12 (Interaction technologies); for A05: T02 (Advanced, or high-performance computing); for A06: T17 (Micro/nanoelectronics) and T22 (Photonics and imaging technologies); for A07: T08 (Cyber security); for A08: T02 (Advanced, or high-performance computing); for A09: T10 (Gamification); for A10: T25 (Screens and display technologies); for A11: T06 (Communication networks); for A12: T18 (Mobility & location-based technologies); for A13: T14 (Internet services); for A14: T15 (Laser-based manufacturing) and T18 (Mobility & location-based technologies); finally for A15: T17 (Micro/nanoelectronics).

In the case of services, unique services are provided by the following actors: for A01: SP12 (Pre-competitive series production); for A02: SP14 (Visioning and strategy development for businesses); for A03: SP04 (Commercial infrastructure), SP06 (Digital maturity assessment), and SP11 (Mentoring); for A04: SP10 (Market intelligence); for A05: SP01 (Access to funding and investor readiness services); for A06: SP12 (Pre-competitive series production); for A07: SP07 (Ecosystem building, scouting, brokerage, networking), SP08 (Education and skills development), and SP09 (Incubator/accelerator support); for A08: SP04 (Commercial infrastructure), SP06 (Digital maturity assessment), and SP11 (Mentoring); for A09, A10, A13, and A14: SP01 (Access to funding and investor readiness services), SP14 (Visioning and strategy development for businesses), and SP15 (Voice of the customer, product consortia); for A11: SP06 (Digital maturity assessment) and SP11 (Mentoring); for A12: SP04 (Commercial infrastructure) and SP06 (Digital maturity assessment); finally for A15: SP15 (Voice of the customer, product consortia). Contrary to centrality measures (see RQ2), the specialization of actors (row exclusivity) in

this approach focuses on DIHs, which have unique (compared to other DIHs) technological and service competences in the region.

5. Limitations and future research

The research was carried out using secondary and publicly available data collected as part of the EU's Smart Specialization Platform tools, including the Digital Innovation Hub. One country (Poland) was taken into account, whose Digital Innovation Hubs profiles were presented in a standardized way through this Platform. The data is primarily declarative, mostly based on submissions from organizations, research centers, and institutions whose idea is to provide technologically advanced digital services that are the domain of European DIH and Industry 4.0. This research area was narrowed down to only two networks: technology and services provided, which in no way exhausts the areas of DIHs analysis operating in the region. The comprehensive research will be the subject of further studies in other EU countries, which will enable comparative measurements, taking into account the measures presented in these studies. This would make it possible to assess what DIHs (in terms of their dominant technologies or services) characterize other EU regions, as well as what their structure and connections are.

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