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AN ANALYSIS OF INTER-ORGANIZATIONAL NETWORK DYNAMICS ON THE EXAMPLE OF ELECTRONIC FREIGHT EXCHANGE

Abstract

Inter-organizational networks are the subject of numerous research projects, which explore not only the importance of companies within a network, its impact on the companies, and the ties between the actors, but also the structure of networks. Due to the rapidly changing environment of organizations, the need arises for an analysis of the dynamics of networks, which can be performed using Dynamic Network Analysis (DNA). The aim of the paper is to propose the use of this method for the analysis of network ties occurring in electronic freight exchange. For this purpose, a model was developed and implemented in a simulation environment. On the basis of selected scenarios, a simulation experiment was carried out. The authors present the most important conclusions from the statistical analysis of the experiments.

Keywords: Dynamic Network Analysis (DNA), network analysis, electronic freight exchange

Introduction

Along with the development of studies of networks in the economy, a growing interest in structural analysis, also called network analysis, became visible. It derives from social network analysis (SNA), whose original subject were the interdependencies and relationships between members of social groups. With regard to companies, the focus is on the relationships between particular persons within organizations, divisions in which they work, or specific teams of employees. Information and knowledge flow paths are analysed, bottlenecks are identified, and, as a result, communication is improved (Kawa, 2014a, p. 47). That being said, more and more often we hear about organization network analysis (ONA) and business network analysis (BNA). The latter, which explores the ties between separate and independent organizations, is especially interesting.

Using SNA to analyse inter-organizational networks requires, however, adopting certain assumptions regarding the subject matter. Companies function differently from members of a community. Information spreads differently in a social and in an economic network. Attempts to adapt SNA to the specifics of management studies have been made for some time now. This research, however, concerns mainly static analyses. They are a photograph of sorts of a network as it is in the given moment. Although stability of such a system is frequently assumed by default, networks are often dynamic and transform in time (Czakon, 2007). Both the ties (e.g. their content, strength, influence, scope) and their configuration as well as the number and type of actors (some join the network, others leave it) are subject to changes. The results of an analysis of a static network thus are of limited use in practice. Some of them can be simply outdated. More and more frequently managers wish to know how their network will look, what will be its structure, and what will be the role of their company in the network once the internal and external environment changes. What is more, they prefer to test different scenarios in a model that reflects particular economic systems rather than to experiment in practice.

In view of the above, network researchers developed a method called dynamic network analysis (DNA), which can be used to analyse network dynamics. It draws on the achievements of SNA and the knowledge from the area of link analysis and multi-agent systems (Carley, 2008, pp. 1324–1347).

The aim of the paper is to propose the use of DNA method for the analysis of network ties occurring in electronic freight exchange. For this purpose, a model was developed and implemented in a simulation environment. On the basis of selected scenarios, a simulation experiment was carried out. The authors present the most important conclusions from the statistical analysis of the experiments.

1. Dynamic network analysis

Dynamic network analysis differs from traditional network analysis in that it explores large networks comprised of many types of ties with varying degrees of uncertainty (Carley, 2002, pp. 206–220). A model of such a network is stochastic, and ties and actors have a probabilistic character. Some nodes and edges appear, others disappear (Rajaraman, 2006). A change in one part of a network can result in a change in other parts or even the whole network.

Dynamic network analysis often uses computer simulations, which make it possible to test different modifications. It is also assumed that particular network links have the ability to learn due to the application of agent technology (Kawa, 2009, pp. 382–389). In such a network, nodes and edges are represented by a program agent that acts and makes decisions autonomously.

DNA is not commonly used by researchers, which is why, unlike SNA, it is not quite as well-developed as a research method yet. It can be said that it is in the early stages of development, as evidenced by a relatively small number of studies and publications as well as the immaturity of the concepts of dynamic network analyses. This probably results from several factors. The most problematic, as in the case of SNA, is the gathering of data on the selected network. The data should be complete, i.e., cover all nodes and ties between them. Another problem is the development of a simulation model, which requires identifying dependent and independent variables as well as putting forward research hypotheses, which usually point to the relationships between the variables. On this basis, an algorithm is developed and then implemented in an appropriate simulation environment. These actions require not only knowledge and experience in modelling economic processes, but also programming skills, which can constitute a barrier for researchers who represent the field of management studies.

However, efforts should be made to make this relatively new research method more commonly used in management studies and economic studies in general. K.M. Carley (2003, p. 134) believes that dynamic network analysis is absolutely indispensable to understand the modern world. We can find numerous examples of dynamic networks. One of them is the Internet, where a multitude of new websites and ties between them are created each day. The network of telecommunication, transport, and organizational ties is also changing. In this latter case we speak of dynamic organizational structures. An example of such a structure is a dynamic supply chain, characterized by changing ties between particular companies that play the role of providers or customers. The Internet – and especially Internet-based IT systems – is increasingly often used as a tool for their configuration. An example of such a system is electronic freight exchange (Wieczerzycki, 2006, pp. 25–38.), which is the subject of this paper.

2. Electronic freight exchange

Electronic freight exchange (EFE) is, in most general terms, a virtual market for companies that offer or look for freight loads to be delivered or cargo spaces. The logic behind electronic freight exchange largely resembles other e-business enabling solutions, such as online shops and auction sites. Their characteristic feature is the automatization of processes and digitalization of documentation (Kawa, 2014b, p. 79).

From an operational perspective, the mechanism of EFE boils down to posting information about transportation and cargo requests, which allows other operators to find an attractive transport service offer and make better use of their cargo space. Electronic freight exchanges are primarily intended for forwarders and carriers, but are also increasingly frequently used by manufacturing and commercial companies (Kawa, 2014b, p. 81).

Initially, electronic freight exchanges were used mainly to conduct one-time transactions and were complementary to other, traditional forms of searching for a counterparty. The exchange was supposed to provide current information about potential providers and customers. However, previous research conducted by the authors indicates that the role of electronic freight exchange for logistics companies has changed during the last few years. Nowadays, thanks to EFE, companies more frequently form long-term ties based on trust and commitment. This is facilitated by the rather restrictive requirements imposed by EFE operators on its potential users (minimum period of operation, set of documents required to conduct activities, etc.). Information provided by credit reference agencies, debtors register, and Internet reviews are also checked (Kawa, 2015, p. 4).

There are numerous electronic freight exchanges in the world – more than a hundred in Europe alone (Majszyk, 2016). Each is used by several to several hundred thousand registered and verified companies. In Poland there are a dozen or so such exchanges, but only three of them – Teleroute, TimoCom, and Trans.eu – are commonly used. The biggest exchanges operate in most European countries. The subject of this paper is Trans.eu, which is briefly described in the next section.

3. Trans.eu

Trans.eu is a Polish electronic freight exchange, established in 2004 in Wrocław by the Logintrans company. Trans.eu is available in twenty languages and used by users from twenty-four European countries. The company has branches in eight European countries. In a year, Trans.eu (2016) publishes more than 35 million offers (82% cargo offers and 18% transportation offers). Since 2005, more than 480 thousand companies from all over Europe have registered. Trans.eu is currently the biggest exchange in Central and Easter Europe and third biggest freight exchange in Western Europe (Romanów, 2011, pp. 43–46).

The subject of this paper is the network of ties between the users of Trans.eu. The content of these ties is the purchase or sale of cargo transportation service or cargo space. The analysis covers 1.07 million transactions registered in 2013 in Poland between 24 thousand companies. The preliminary analysis indicated that 85% of them were one-time transactions. What is more, there are many single (consisting of repeated transactions) ties between transport service providers and their customers within the Trans.eu system. Only 46% of users cooperated with at least two other companies, 0.5% (97% of them were forwarders) cooperated with at least a hundred other companies, and 1.8% – with at least fifty. The average number of counterparties of the network users was 10.5. Forwarding companies had the most ties to other users. The biggest of them cooperated with four hundred and sixty-six other users. These data attest to the high diversification of exchange participants.

After conducting a preliminary network analysis of Trans.eu we can distinguish many so-called components – independent clusters of interrelated actors disconnected from other network clusters. The biggest component consisted of 23 thousand users and more than 840 thousand ties between them. Such a component, comprised of vertices and edges, is a networked structure, which makes it possible to determine the degree of its connectivity, i.e., the number of ties between the actors, their density, the distance between the actors, etc.

4. Issues and research procedure

As already mentioned, the results of the author's previous research among the participants of Trans.eu show that they increasingly often form long-term ties, of both a formal and informal character (Kawa, 2015, pp. 2–9). On the other hand, an in-depth social network analysis indicates that companies engage in manifold – direct and indirect, horizontal and vertical – relationships (Fuks, Kawa, Pierański, 2015, pp. 151–159). Within the Trans.eu environment thus emerged a specific network comprised of separate companies providing and using transport services. This network, however, is subject to changes. On the one hand, the exchange environment is stabilizing; on the other, it is constantly expanding. Each year it is joined by new users. This increases competition, as the customers have a wider choice of logistics service providers, and they increase the number of their potential customers. This also benefits the exchange operator, because every new user has to pay for using the system. There is, however, a growing risk that there will be dishonest or unreliable counterparties among the new users, whose activities will lead some of the important – from the perspective of the operator and the network itself – users to resign from the service. This can cause a chain reaction, making companies dependent on those users also leave the network. Those "important" users are the so-called centralized actors, which concentrate a relatively large number of other actors (network nodes).

A safer solution seems to be to develop the exchange by means of increasing its connectivity. This can be done by creating new ties to actors with which other users (customers, service providers, and competitors from a particular company) already cooperate. Thus, a question arises if, from the point of view of the operator, it is worth to increase the number of ties between the users. Dynamic network analysis served to provide an answer. Before conducting an analysis using the DNA method, however, a simulation network model has to be developed.

For the purposes of the research process, the authors proposed three strategies, which from an operational perspective constitute experimental factors, i.e., independent variables. Changes that occur under the influence of the introduced experimental factor constitute dependent variables (Apanowicz, 2002, p. 64.). The developed strategies concern the way of building a network depending on the tendency to increase the number of ties by exchange participants:

1) openness strategy: there is full freedom of creating new ties,
2) lockdown strategy: creation of new ties is put on hold,
3) regulation strategy: mix of the two.

With regard to the earlier presented research problem, a hypothesis can be formulated that openness to the creation of new ties between the users increases the connectivity of the EFE network. SNA measures, such as network density, diameter, clustering coefficient, small-world effect, will serve to determine the degree of connectivity.[8] These measures are the dependent variables.

The analysis considers long-term ties, which in strategic management constitute a prerequisite for establishing network ties (Klimas, 2014). However, it is difficult to unequivocally determine which ties are long-term. They definitely go beyond one-time, sporadic, and thus unrepeated transactions. The authors arbitrarily assume that for their relationships to be long-term, the same companies have to conduct at least ten transactions per year. This allowed to limit the number of actors to 978, out of which 761 constitute a big component, i.e., a tight-knit network. Further network analysis provided information about the density, diameter, clustering coefficient, and small-world effect.

The density of the network is the total number of ties divided by the number of possible ties. It is also often called network completeness. Density of 0.0042 means that the network is complete in 0.42%. The potential of the analysed network in terms of the number of ties remains largely unexploited. The relatively low density is, however, characteristic of economic networks. Additionally, the density of such networks decreases as the number of nodes grows – a given actor is unable to or not interested in cooperation with all other actors, especially that some of them are its competitors.

The diameter of the network is the maximum shortest path length between all the possible pairs of the network nodes. It is determined based on the path length between two most distant nodes (the path length between another randomly selected pair of nodes is smaller than the diameter of the network). Within the analysed network, the hop count between the two most distant nodes is 13 (there are twelve other nodes between them). This high value indicates the existence of peripheral nodes and impairs the connectivity of the studied object.

Clustering coefficient is the number of all closed triplets (so-called cliques) over the total number of connected triplets (both closed and open, i.e., consisting of three nodes and two edges). Clustering coefficient of 0.0112 means that 1.12% of all cliques (at least three nodes) are fully connected. There are relatively few such connections between any three nodes within the analysed network. A higher value would indicate a higher degree of connectivity.

Small-world effect is the average shortest path length between any two nodes. The large number of network participants means that in the vast majority of cases they are interconnected through indirect ties. The value of 5.126 means that any two nodes can reach one another in five steps (i.e., four additional ties). This is a relatively high value, even for an inter-organizational network. The higher the value, the lower the degree of connectivity (Fuks, Kawa., Pierański, 2014, pp. 47–53).

In the next step of the analysis, the ties between the nodes were mapped. Three clusters emerged as a result of network visualization using a heat map, in which a dominant role is played by forwarders (central nodes). These clusters are connected through so-called bridges created by forwarders and transportation companies with which they cooperate.

8 For a more in-depth description see: (Fuks, Kawa, Pierański, 2014, pp. 47–53).

The next step of the study required choosing the simulation environment in which the model was to be implemented and the experiment carried out. The authors decided to develop the simulation from scratch using the Python programming language (release 2.7.4). For a better analysis and network visualization, the NetworkX Python library was used. NetworkX allows to create, change, and study the structure, dynamics, and functions of highly complex networks. It is equipped with numerous business dictionaries and structural analysis measures. It also allows to generate pseudorandom numbers, import and export data, and visualize networks. Thanks to the implementation of his own algorithms, the programmer can perform simulation experiments within the studied network (NetworkX, 2016).

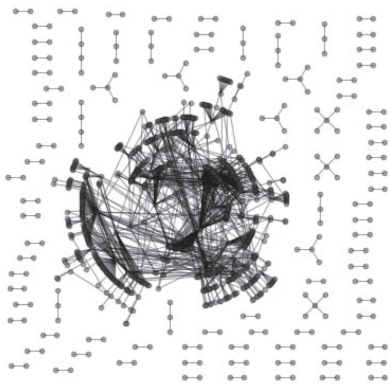

Figure 1. Ties between companies that conduct at least ten transactions per year with the same actors within Trans.eu
Source: (own elaboration)

Figure 2. Heat map of the ties between the users of Trans.eu
Source: (own elaboration)

5. Simulation experiment

In accordance with the procedure of carrying out scientific research in the form of a simulation experiment, after having identified the research problem, formulated the hypothesis, identified the variables, and chosen the programming environment, a simulation model has to be developed and implemented, and a simulation experiment performed (Stańczyk-Hugiet, 2013, pp. 64–77).

As already mentioned, the simulation model developed for the purpose of the study consists of an independent variable in the form of a strategy of action and dependent variables expressed by the SNA measures. The presented strategies translate into the scenarios of the performed simulation experiments implemented by the authors from scratch in the Python programming language using the NetworkX library. These are:

1) openness scenario: the ties between the nodes are established at random. The only criterion that has to be met is the transportation route serviced by the provider (country of origin – country of destination), i.e., for a service provider to be considered, it has to service the route indicated by the job parameters;
2) lockdown scenario: ties are created primarily from the base of service providers with which the given actor has already established long-term cooperation. The prerequisite is, of course, that the provider services the given route; otherwise an actor is selected from the total pool of service providers (scenario 1);
3) regulation scenario: the probability of randomness is determined, e.g. a probability of 20% means that 20% of transactions will be random (scenario 1), and 80% – preferential (scenario 2).

Based on the above scenarios, the following simulation algorithm has been developed:

1) for each service provider and service recipient, a transaction list is compiled which stores the following data:
   - date of the transaction (a key that identifies the particular lines on the list),
   - total number of transactions on the given day,
   - data regarding the country of origin and the country of destination (which determines routes for the service provider and job parameters for the service recipient);
2) for each service recipient, all offers are taken into account and processed, and a new network is created on this basis;
3) for each offer, a list of potential service providers is compiled based on the country of origin and the country of destination;
4) if the list is not empty, the system selects a service provider according with a given scenario;
5) a tie is established in the new network between the service recipient and the chosen service provider;
6) the procedure is repeated from point 3, unless the given service recipient presents no other offers, in which case the procedure is repeated from point 2, i.e., another service provider is chosen.

The described procedure was repeated many times. The subsequent iteration depended on the value of the random parameter (corresponding to the random scenario), increased by 1 in the range [0, 5) and by 5 in the range [5, 100].

As a result of the performed simulation experiment data was obtained which was then exported to external files. The data concerned the structure (the vertices of a given network tie) and parameters of the network (described in the previous paragraphs) defined in a programming language using the NetworkX library. The data were imported into a MS Excel spreadsheet and analysed statistically. The results are illustrated as graphs.

Figures 3–6 present the changes in the network parameters as a result of increasing the value of the random parameter. Figures 7–9 present network visualizations with the random parameter value of 1, 3, and 20, respectively.

The random parameter value of 0 indicates a complete implementation of the lockdown strategy (no random ties). As already noted, such a network is characterized by the following values: density (0.0042), diameter (13), clustering coefficient (0.0112), and small-world effect (5.126). An increase of the value of the random parameter (transition from the lockdown strategy towards the openness strategy) to ca. 3% results in lower values of connectivity measures. The diameter of the network and the small-world effect measure increase, while the density and the clustering coefficient decrease. The value of ca. 3% is a border point – for this value of the random parameter, the values of connectivity are similar to those for the original network. This means that at the initial stage of implementing the openness strategy the studied object becomes "disnetworked," i.e., the actors strengthen their ties to their current, most reliable partners.

As a result of implementing the regulation strategy, subsequent iterations improve the values of connectivity measures. The changes, however, are the most pronounced when there are between ca. 3% and ca. 20% of random ties. This means that along with the transition from the lockdown strategy towards the openness strategy the degree of connectivity of the studied object increases significantly. With ca. 20% to 100% of random ties these measures continue to increase and still have a positive influence on connectivity, but to a lesser degree (with accordance to the principle of diminishing marginal benefit).

The next step was to measure the statistical dependence between the independent variable (random parameter) and the dependent variables (network measures). There is a strong correlation between the random parameter, the density measure, and the clustering coefficient (0.99 and 0.97, respectively). Correlation coefficients are also high for network density and small-world effect (–0.82 and –0.99, respectively). All correlations are statistically significant at the $p < 0.001$ level (two-tailed).[9]

The above dependencies and conclusions confirm the research hypothesis, which posited that openness in terms of establishing ties between the users of electronic freight exchange increases its connectivity. The openness strategy, which consists in increasing the number of new, but reliable companies, has a positive effect on the network, increasing its stability and resilience to structural changes. It also increases the competitiveness of both service providers and service recipients.

[9] Spearman's Rho tests were used to check the statistical significance of the investigated features.

The lockdown strategy, on the other hand, by prohibiting the establishment of new ties, results in the actors' growing dependence on other companies and increases the risk of failure; for instance, resignation or bankruptcy of one of the service providers and service recipients can seriously disrupt the current operations of a company.

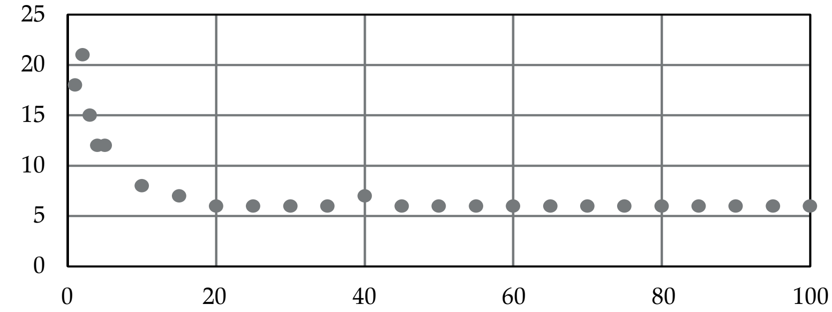

Figure 3. Dynamics of changes in network diameter with an increasing value of the random parameter
Source: (own elaboration)

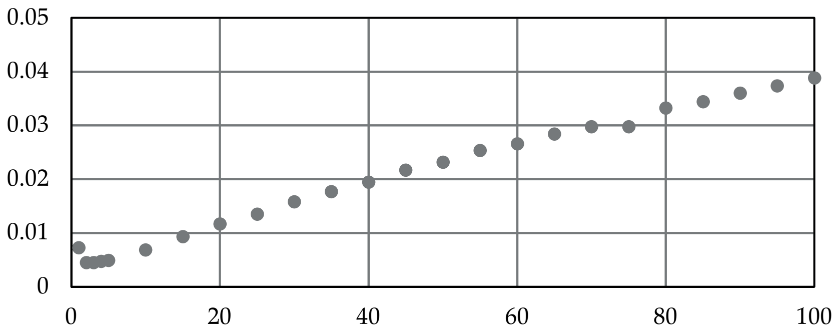

Figure 4. Dynamics of changes in network density with an increasing value of the random parameter
Source: (own elaboration)

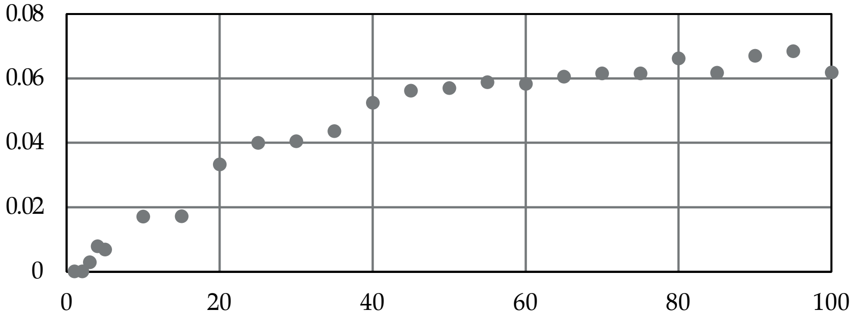

Figure 5. Dynamics of changes in clustering coefficient with an increasing value of the random parameter
Source: (own elaboration)

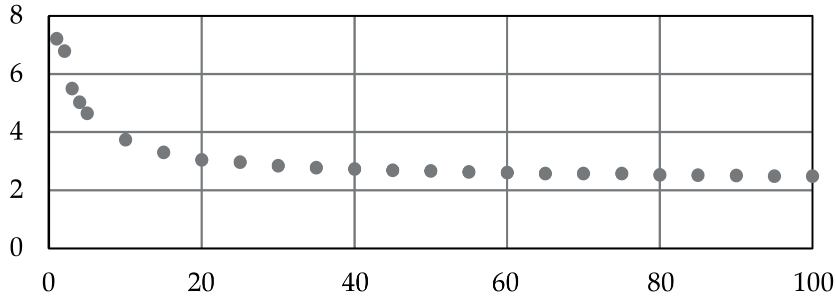

Figure 6. Dynamics of changes in small-world effect with an increasing value of the random parameter
Source: (own elaboration)

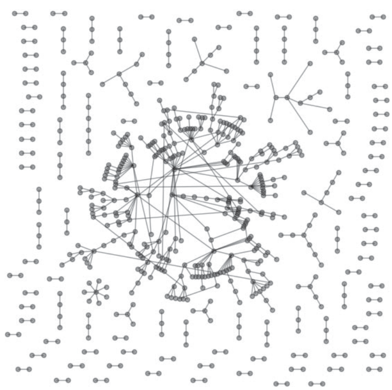

Figure 7. Network visualization with the random parameter value of 1
Source: (own elaboration)

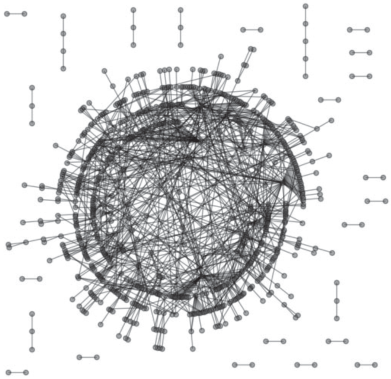

Figure 8. Network visualization with the random parameter value of 3
Source: (own elaboration)

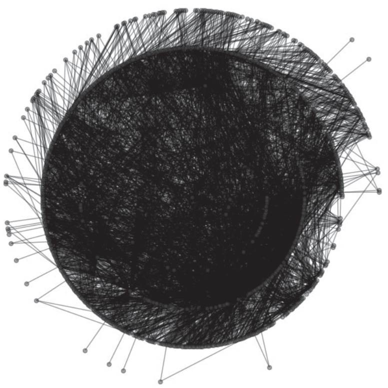

Figure 9. Network visualization with the random parameter value of 20
Source: (own elaboration)

Conclusions

In the modern economy, not only companies, but also the relationships between them are subject to rapid changes. If an organization directly or indirectly establishes both formal and informal ties to different types of actors, those ties can form a network and become the subject of numerous studies.

Static network analysis is well-covered in literature, although it is the opinion of the authors that there is a shortage of empirical research, especially with regard to inter-organizational networks (the perspective of economic systems). Due to the dynamic character of the networks, the SNA method is insufficient. The concept of dynamic network analysis comes to the aid, which allows to analyse networks taking into account the changing internal and external environment by using computer simulations. It also allows to register the interactions and behaviours that are difficult to observe in reality (Balcerak, Kwaśnicki, 2005, pp. 5–15). Moreover, simulation experiments are a safer solution than testing scenarios on a "living" organization.

The authors of the paper used the DNA method to study the network of the electronic freight exchange Trans.eu. For the purpose of the study, three scenarios have been distinguished and used to analyse the dynamics of the network. The performed simulation experiment confirmed the hypothesis that posited a correlation between the implementation of the openness strategy and the connectivity of the network.

The model presented in the paper allows to carry out simulation experiments in a specific inter-organizational network. The model is fairly universal and can be of use for studies of similar objects. Its adaptation requires, however, certain modifications and additional assumptions characteristic for the given network. Each time the validity of their application needs to be considered due to the complexity of the algorithmization and codification process in the simulation environment. Nevertheless, it is still a much faster and cheaper method than the verification of scenarios under real conditions.

Although the paper confirms the validity of using the DNA method to analyse inter-organizational networks, it needs to be remembered that it has certain limitations. First of all, it requires the researcher to be acquainted with the SNA method and possess to ability to model and perform simulation experiments. This barrier can be eliminated by creating interdisciplinary research teams, in which the cooperation of researchers from two or more scientific disciplines results in a synergy of economic and IT competencies.

A disadvantage of simulation experiments is that they do not provide precise information about how the system will act in reality, but only indicates its typical, i.e., most probable, behaviour (Mielczarek, 2005, pp. 133–141). What is more, it requires adopting many assumptions that can grossly simplify and even distort the studied object, which is why simulation experiments are regarded as an abstraction of reality.

The main element taken into account when analysing socio-economic phenomena is man, whose behaviour is not always predictable and rational. Attention should be paid to the scope and strength of man's influence on the simulation model and the course of the simulation experiment (Kawa, Fuks, Januszewski, 2016, pp. 109–126). When analysing a phenomenon from the level of a community, a group, or a network (and not an individual), the results of simulation experiments are more predictable.

It is therefore the authors' opinion that the use of simulation experiments to analyse the dynamics of socio-economic networks is the most suitable research method, which can be successfully used to test hypotheses formulated in scientific studies.

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