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An introduction to the state-of-the-art review of social network-based manufacturing system

Social network analysis definitions, terminology and application areas

Abstract

Social network-based manufacturing system (SNMS) is a new emergent manufacturing paradigm based on social networks aiming to promote the creation of increasing returns and the achievement of a triple bottom line sustainability. This paper presents an introduction to the concept and to the SNMS state-of-the-art review, considering a meta-theoretical framework – the SNMS abstraction hierarchy meta-theoretical framework. This meta-theoretical framework has 5 hierarchical levels but, for this paper, only part of the first hierarchal level is presented, i.e. the social network analysis definitions, terminology and application areas. The remaining hierarchical levels are referred as future work directions.

Keywords

Social network-based manufacturing system; social network analysis; state-of-the-art; meta-theoretical framework; abstraction hierarchy framework

1. Introduction

As the result of the increasing market globalization, small and medium enterprises (SMEs) have to explore the external cooperation and collaborative manufacturing networks to increase their competitiveness (Zeng et al., 2010). Those manufacturing networks have emerged as a key strategy for SMEs since they facilitate the accelerated flows of information, resources and trust (Dewick & Miozzo, 2004). In the last years, the term "social network" has been more frequently used in organizations. A social network consists of a set of actors along with a set of ties of a specified type that link those actors (Borgatti & Halgin, 2011).

The social network paradigm has already been applied for enhancing different business areas, such as education and healthcare (Cruz-Cunha et al., 2011). However, its use in manufacturing is still on the beginning (Putnik & Cunha, 2008). Putnik et al. (2013), in their keynote paper for the International Academy for Production Engineering (CIRP), present a Roadmap for future research that explicitly includes the exploration of crowdsourcing, Web 3.0 and Web 4.0, and social networks in manufacturing.

Abbasi et al. (2012) referred that social networks can be used to identify strengths and weaknesses within and among organizations and businesses, to understand how organizations are run and to realize how markets evolve. Other uses of social networks in organizations can be found in (Borgatti & Li, 2009), where the authors used social network concepts for supply chain management, and in (Vrabic et al., 2012) for an application of

social networks for discovering autonomous structures within manufacturing systems.

The emergence of manufacturing systems based on social networks creates conditions for the development of new manufacturing systems paradigms, such as the social network-based manufacturing system (SNMS). This paradigm can face other emergent concepts of increasing resources sharing and increasing trust levels between partners, and of development of Information and Communication Technologies (ICT).

SNMS is based on the exploration of social networks and enables the new organizations, the non-linear (''flow'' organizations), to pass through the transformative changes, as the basis for expecting network and social interaction effects, to create increasing returns and triple bottom line (3BL) sustainability. Increasing returns occurs when an output of a specific economic system increases more than proportionally with a rise of input (Den Hartigh, 2005). The 3BL sustainability, i.e. the economic, environmental and social sustainability, is considered as an important aspect to create more sustainable manufacturing systems in companies (Gimenez et al., 2012).

SNMS can be considered as a new instrument for the endogenous economic growth theory. This paradigm might be more competitive than, in general, the more trusted exogenous economic growth theory (e.g. economic growth based on external investments).

This paper presents the concept of SNMS through an introduction of its state-of-the-art review. For this purpose, an abstraction hierarchy meta-theoretical framework is used, consisting of 5 hierarchical levels. The paper describes one of the parts of the first hierarchal level, i.e. the social network analysis definitions, terminology and application areas.

2. Relevance

To evaluate the relevance of SNMS, a first analysis might be made through the references to SNMS by the research community. For this evaluation, there are two decisions to make (Montoya-Torres & Ortiz-Vargas, 2014): (i) select the search engine; and (ii) choose the search criteria. To identify relevant papers the following world leading publishers were used:

- Springer;
- Elsevier;
- Taylor & Francis;
- Emerald;
- JSTOR;
- Wiley.

Most of these publishers' databases are widely accessible for academic institutions and have been used in similar studies (e.g. Putnik et al., 2013; Montoya-Torres & Ortiz-Vargas, 2014). Figure 1 presents the number of papers (articles and chapters) in collections of the selected publishers per year, using the search term "social network AND manufacturing system". The data is related to the last 20 years (1995-2014) and considering the first three trimesters of the year 2014.

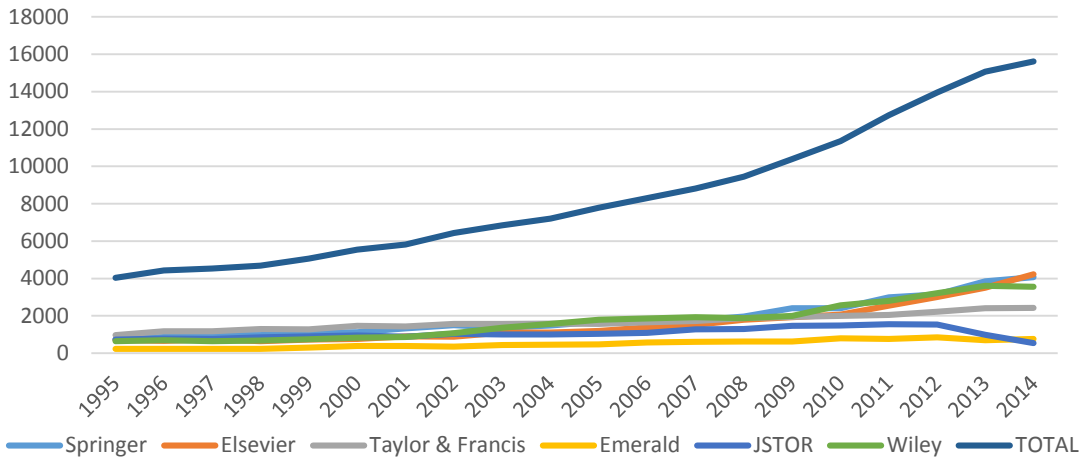

Figure 1. Number of papers in world leading publishers using the search terms "social network AND manufacturing system"

The analysis of some of the most important publication sources shows that the issue of "social networks" within the manufacturing community has started to gain major attention in the last decade. Despite only being represented the first three trimesters of the year 2014, in most of the analyzed publishers, 2014 represents the year with the highest number of published papers.

The relevance of SNMS can also be evaluate through some significant international R&D Programs. The occurrences of the topics "networks" and "social networks" under the subject of "Industrial Manufacture" can be assessed considering some European research projects at the CORDIS[1] (Community Research and Development Information Service) platform, e.g. HIGHTECH EUROPE[2], BENISI[3], FLEXINET[4], and TRANSITION[5].

3. Meta-theoretical frameworks for the SNMS issue presentation

3.1. Meta-theoretical frameworks

According to Love (2000), a meta-theoretical framework creates a structure to relate elements of different theories and concepts. The purposes of using a meta-theoretical framework for SNMS are: (i) to provide a better understanding of the concept of SNMS; (ii) to improve the capability for effective and efficient development, implementation and validation of SNMS.

To study the concept of SNMS, different meta-theoretical frameworks can be used: (i) using a more traditional approach, referring to SNMS functional and application domains; (ii) using a SNMS abstraction hierarchy. For the presentation of SNMS, the selection of one of these meta-theoretical framework is an arbitrary choice since there is no specific objectives of the presentation. For this paper, the SNMS abstraction hierarchy meta-theoretical framework is selected.

3.2. SNMS abstraction hierarchy meta-theoretical framework

The abstraction hierarchy meta-theoretical framework (Love, 2000) presents, in a hierarchical ordering, a taxonomy of abstractions with the purpose of externalize hidden dependencies between underlying concepts, elements and constructs of a theory.

[1] European Commission CORDIS platform: http://cordis.europa.eu/home_en.html

[2] EU Research Project HIGHTECH EUROPE: http://cordis.europa.eu/project/rcn/90532_en.html

[3] EU Research Project BENISI: http://cordis.europa.eu/project/rcn/109095_en.html

[4] EU Research Project FLEXINET: http://cordis.europa.eu/project/rcn/108887_en.html

[5] EU Research Project TRANSITION: http://cordis.europa.eu/project/rcn/110395_en.html

The SNMS abstraction hierarchy meta-theoretical framework is expressed in 5 hierarchical levels:

I. Description
II. Models and behavior
III. Mechanisms of choice
IV. Methods and tools
V. Epistemology

The detail of each hierarchical level is described in Table 1.

Table 1. SNMS abstraction hierarchy meta-theoretical framework.

Hierarchical level	Name	Detail
I	Description	Definitions and terminology of SNMS and of all related research areas, such as networks, social networks, social network analysis (SNA), increasing returns and 3BL sustainability.
		Application areas of SNMS and of all related research areas, such as manufacturing systems, computer science, economics, supply chain management (SCM), logistics, healthcare and education.
II	Models and behavior	Models and functions of SNMS, such as models of the network theory and social network analysis instruments, the increasing returns theory, the 3BL sustainability and SNMS.
		Performance measures of SNMS, such as throughput time and/or time-to-market (TTM), reduction of CO2 emission, employment potential, and increase of output as function of a rise of input.
III	Mechanisms of choice	SNMS management, i.e. organizing, planning, controlling, and directing the system using a number of methods and tools, such as lean and agile SNMS, real time management (RTM), concurrent and collaborative SNMS, scalable SNMS, and Big Data management.
IV	Methods and tools	Implementation of models of SNMS in the following representation classes: social network diagram, SNA formalisms, network theory formalisms, structural equation model (SEM), and production functions for increasing returns.
		Software tools for implementation, such as UCINET, SPSS, Amos, Matlab, and Excel.
V	Epistemology	How the knowledge on SNMS is acquired and used, validity and coherence of knowledge on SNMS in social context, SNMS phenomenology, critique, human and social dimension, and other epistemological issues.

For this paper, only part of the first hierarchical level (I – Description) is presented, i.e. the main definitions and terminology of SNA, as well as some SNA applications areas.

4. Description

4.1. SNA definitions and terminology

SNA is an approach and a set of quantitative methods and techniques for systematically analyzing and mapping relations (ties) between social entities or actors (individuals, groups or organizations), as well as to study the exchange of resources among those actors (Wasserman, 1994; Kim et al., 2011; Smythe et al., 2014). SNA consists of 3 main stages (Ting & Tsang, 2014):

1) Describe the set of actors of the network;
2) Characterize the relationships between actors;
3) Analyze the network structure of the relationships.

Freeman (2004) presents 4 key assumptions for SNA: (i) is motivated by "structural intuition" which is based on the ties linking social actors; (ii) is based on systematic empirical data; (iii) is based on the use of mathematics and/or computational models; and (iv) relies largely on graphics.

Cimenler et al. (2014) state that SNA is a method used to reveal the structure of collaboration between actors. Borgatti (2006) refers that an important aspect in SNA is to identify key players in a social network. Hence, many SNA measures are used to analyze structures of collaboration and key players in social networks. These SNA measures are divided into individual and group-level measures (Sauer & Kauffeld, 2013). The main individual SNA measures are centrality measures and the main group SNA measures are cohesion and subgroup measures.

Centrality measures describe aspects of specific nodes or actors in the network (Kjos et al., 2013), identifying the most prominent actors, i.e. those extensively involved in relationships with other network members (Freeman, 1979). Frequently used centrality measures include degree centrality, betweenness centrality, closeness centrality, and eigenvector centrality. Degree centrality corresponds to the number of direct ties an actor has (Borgatti, 1995). Betweenness centrality is defined as the possibility of being an intermediary in communication between other nodes (Gómez et al., 2013). Closeness centrality depicts how close the actor is to other group members (Opsahl et al., 2010). Eigenvector centrality calculates a type of relative importance, i.e. important nodes must be neighbors of other important nodes (Ai et al., 2013).

Cohesion measures are used to describe properties of the whole network and are focused on the integration of the network (Kjos et al., 2013). The main measures of cohesion are the density of the network and the network centralization. The network density corresponds to the number of realized ties divided by the number of possible ties in the network (Wey et al., 2008). The centralization depicts to what degree interaction revolves around a highly central actor (Sauer & Kauffeld, 2013).

Subgroup measures show how a network can be partitioned (Hawe et al., 2004). Subgroups can be identified within the network and can provide important information to understand the influence of the subgroup on the overall network and on the egocentric network (Wang & Chiu, 2008). Various measurement methods can be applied to identify subgroups in a network, such as measurements of component, clique, k-plex, and k-cores.

4.2. SNA application areas

SNA is a multidisciplinary approach where the tools are similar for any self-organizing autonomous complex network (Borg et al., 2014). The approach has been developed and tested in various fields, contributing with novel insights through the relationship-based approach (Wey et al., 2008). SNA can be used as a tool to investigate organizational structures, financial transactions, the spread of disease, the relationships between genes, and in general any field of study where the connections between entities is important (Wasserman, 1994). In supply-chain analysis, the use of SNA is focused on network inter-dependences and emphasizes the impact of the network structure on firm competitiveness (Sloane & O'Reilly, 2013). Table 2 presents some examples of SNA applications in several research areas.

Table 2. Examples of SNA application areas.

Publication	Research area	SNA application
Sloane & O'Reilly (2013)	Supply networks	Explore the evolution and impact of both positional and structural characteristics of supply networks (supplier, service, customer, alliance and competitive relations) on member strategy and network performance.
Ting & Tsang (2014)	Supply chain management	Analyze supply chains for the identification of parties that are likely to be involved in counterfeiting activities and prevent sources of counterfeit products from infiltrating into the supply chain.
Houghton et al. (2006)	Ergonomics	Explore processes of command and control in the emergency services (fire service operations and police operations).
Kim et al. (2011)	Knowledge management	Implementation of a Knowledge Brokering System to enlarge the competitive advantages of firms by using effective knowledge transfer.
Dreżewski et al. (2014)	Information science	Construct and analyze social networks during an investigation into money laundering cases, assigning roles to persons from the network and allowing for analysis of connections between them.
Smythe et al. (2014)	Marine resource management	Application to collaborative marine ecosystem-based management planning, with focus on network structure and the role and influence of individual actors within their respective planning networks.
Mohammadfam et al. (2014)	Work safety	Examine the coordination status among response teams and provide a main opportunity for managers and planners to have a clear understanding of the presented status.
Mandarano (2009)	Society and natural resources	Evaluate collaboration's effectiveness at building social capital.
Borg et al. (2014)	Forest biodiversity conservation	Analyze the structure of a cooperative network for forest conservation and describe the network positions of individual organizations and the macro-structure emerging from organizations independently establishing contacts in the network.
Bian et al. (2014)	Biomedical informatics	Investigate the effectiveness of the collaboration network of a research institution with a Clinical and Translational Science Award (CTSA).
Kornienko et al. (2014)	Behavioral biology	Investigate associations between hormones and social network structures.
Wey et al. (2008)	Animal behavior	Identifying and quantifying specific attributes of social relationships, such as group size, in animal behavior.
Quinn et al. (2012)	Social services	Applied as a research and assessment tool for use by the social services, particularly when examining group dynamics.
Abbasi et al. (2011)	Co-authorship networks	Identify the effects of co-authorship networks on the performance of scholars.
Toikkanena & Lipponen (2011)	Education	Analyze the learning interactions of a group of students in a virtual learning environment.
Sauer & Kauffeld (2013)	Communication	Analyze the internal activities of a small group interaction and explore important features that depend on the relations between members.
Pryke (2004)	Construction management	Comparative analysis of procurement and project management of construction projects; compare traditional project coalition management approaches with innovative management approaches.

5. Conclusion

This paper describes the definitions, terminology and application areas of SNA, which correspond to a part of the first hierarchal level of the SNMS abstraction hierarchy meta-theoretical framework. Nonetheless, the other parts of the first hierarchal level of the SNMS meta-theoretical framework must be developed with the definitions, terminology and application areas of networks, social networks, increasing returns and 3BL

sustainability. Further research must be done on the other 4 hierarchal levels of the SNMS abstraction hierarchy meta-theoretical framework, i.e. the Models and behavior, Mechanisms of choice, Methods and tools, and Epistemology. Special attention should be given in SNMS to issues such as modeling of network effects and social interaction effects, social network self-organization and social network properties as function of size and dynamics, performance measures, and their inter-relationship.

References

Abbasi, A., Altmann, J., & Hossain, L. (2011). Identifying the effects of co-authorship networks on the performance of scholars: A correlation and regression analysis of performance measures and social network analysis measures. *Journal of Informetrics*, *5*(4), 594-607.

Abbasi, A., Hossain, L., & Leydesdorff, L. (2012). Betweenness centrality as a driver of preferential attachment in the evolution of research collaboration networks. *Journal of Informetrics*, *6*(3), 403-412.

Ai, J., Zhao, H., Carley, K., Su, Z., & Li, H. (2013). Neighbor vector centrality of complex networks based on neighbors degree distribution. *The European Physical Journal B*, *86*(4), 1-7.

Bian, J., Xie, M., Topaloglu, U., Hudson, T., Eswaran, H., & Hogan, W. (2014). Social network analysis of biomedical research collaboration networks in a CTSA institution. *Journal of biomedical informatics*, (Article in press).

Borg, R., Toikka, A., & Primmer, E. (2014). Social capital and governance: a social network analysis of forest biodiversity collaboration in Central Finland. *Forest Policy and Economics*, (Article in press).

Borgatti, S. (1995). Centrality and AIDS. *Connections*, *18*(1), 112-114.

Borgatti, S. (2006). Identifying sets of key players in a social network. *Computational & Mathematical Organization Theory*, *12*(1), 21-34.

Borgatti, S., & Li, X. (2009). On Social Network Analysis in a Supply Chain Context. *Journal of Supply Chain Management*, *45*(2), 5-22.

Borgatti, S., & Halgin, D. (2011). On network theory. *Organization Science*, *22*(5), 1168-1181.

Cimenler, O., Reeves, K. A., & Skvoretz, J. (2014). A regression analysis of researchers' social network metrics on their citation performance in a college of engineering. *Journal of Informetrics*, *8*(3), 667-682.

Cruz-Cunha, M., Gonçalves, P., Lopes, N., Miranda, E., & Putnik, G. (2011). *Handbook of research on business social networking: Organizational, managerial, and technological dimensions*. IGI Global.

Den Hartigh, E. (2005). *Increasing returns and firm performance: an empirical study*. Doctoral thesis, Erasmus University Rotterdam, Netherlands.

Dewick, P., & Miozzo, M. (2004). Networks and innovation: sustainable technologies in Scottish social housing. *R&D Management*, *34*(3), 323-333.

Dreżewski, R., Sepielak, J. & Filipkowski, W. (2014). The application of social network analysis algorithms in a system supporting money laundering detection. *Information Sciences*, (Article in press).

Freeman, L. (1979). Centrality in social networks conceptual clarification. *Social networks*, *1*(3), 215-239.

Freeman, L. (2004). *The development of social network analysis: A study in the sociology of science*. Vancouver: Empirical Press.

Gimenez, C., Sierra, V., & Rodon, J. (2012). Sustainable operations: Their impact on the triple bottom line. *International Journal of Production Economics*, *140*(1), 149-159.

Gómez, D., Figueira, J. R., & Eusébio, A. (2013). Modeling centrality measures in social network analysis using bi-criteria network flow optimization problems. *European Journal of Operational Research*, *226*(2), 354-365.

Hawe, P., Webster, C., & Shiell, A. (2004). A glossary of terms for navigating the field of social network analysis. *Journal of epidemiology and community health*, *58*(12), 971-975.

Houghton, R. J., Baber, C., McMaster, R., Stanton, N. A., Salmon, P., Stewart, R., & Walker, G. (2006). Command and control in emergency services operations: a social network analysis. *Ergonomics*, *49*(12-13), 1204-1225.

Kim, S., Suh, E., & Jun, Y. (2011). Building a Knowledge Brokering System using social network analysis: A case study of the Korean financial industry. *Expert Systems with Applications*, *38*(12), 14633-14649.

Kjos, A., Worley, M., & Schommer, J. (2013). The social network paradigm and applications in pharmacy. *Research in Social and Administrative Pharmacy*, *9*(4), 353-369.

Kornienko, O., Clemans, K., Out, D., & Granger, D. (2014). Hormones, behavior, and social network analysis: Exploring associations between cortisol, testosterone, and network structure. *Hormones and behavior*, *66*(3), 534-544.

Love, T. (2000). Philosophy of design: a meta-theoretical structure for design theory. *Design studies*, *21*(3), 293-313.

Mandarano, L. (2009). Social network analysis of social capital in collaborative planning. *Society and natural resources*, *22*(3), 245-260.

Mohammadfam, I., Bastani, S., Esaghi, M., Golmohamadi, R., & Saei, A. (2014). Evaluation of Coordination of Emergency Response Team through the Social Network Analysis Case Study: Oil and Gas Refinery. *Safety and Health at Work*, (Article in press).

Montoya-Torres, J., & Ortiz-Vargas, D. (2014). Collaboration and information sharing in dyadic supply chains: A literature review over the period 2000–2012. *Estudios Gerenciales*, (Article in press).

Opsahl, T., Agneessens, F., & Skvoretz, J. (2010). Node centrality in weighted networks: Generalizing degree and shortest paths. *Social Networks*, *32*(3), 245-251.

Pryke, S. D. (2004). Analysing construction project coalitions: exploring the application of social network analysis. *Construction Management and Economics*, *22*(8), 787-797.

Putnik, G., & Cunha, M. (2008). *Encyclopedia of networked and virtual organizations (Vol. 1 & Vol. 2)*. Information Science Reference.

Putnik, G., Sluga, A., ElMaraghy, H., Teti, R., Koren, Y., Tolio, T., & Hon, B. (2013). Scalability in manufacturing systems design and operation: State-of-the-art and future developments roadmap. *CIRP Annals - Manufacturing Technology*, *62*(2), 751-774.

Quinn, A., Woehle, R., & Tiemann, K. (2012). Social Network Analysis for Analyzing Groups as Complex Systems. *Journal of Social Service Research*, *38*(5), 605-618.

Sauer, N., & Kauffeld, S. (2013). Meetings as networks: Applying social network analysis to team interaction. *Communication Methods and Measures*, *7*(1), 26-47.

Sloane, A., & O'Reilly, S. (2013). The emergence of supply network ecosystems: a social network analysis perspective. *Production Planning & Control*, *24*(7), 621-639.

Smythe, T., Thompson, R., & Garcia-Quijano, C. (2014). The inner workings of collaboration in marine ecosystem-based management: A social network analysis approach. *Marine Policy*, *50*, 117-125.

Ting, S., & Tsang, A. (2014). Using social network analysis to combat counterfeiting. *International Journal of Production Research*, *52*(15), 4456-4468.

Toikkanen, T., & Lipponen, L. (2011). The applicability of social network analysis to the study of networked learning. *Interactive Learning Environments*, *19*(4), 365-379.

Vrabič, R., Husejnagić, D., & Butala, P. (2012). Discovering autonomous structures within complex networks of work systems. *CIRP Annals-Manufacturing Technology*, *61*(1), 423-426.

Wang, J., & Chiu, C. (2008). Recommending trusted online auction sellers using social network analysis. *Expert Systems with Applications*, *34*(3), 1666-1679.

Wasserman, S. (1994). *Social network analysis: Methods and applications*. Cambridge: Cambridge University Press.

Wey, T., Blumstein, D., Shen, W., & Jordán, F. (2008). Social network analysis of animal behaviour: a promising tool for the study of sociality. *Animal Behaviour*, *75*(2), 333-344.

Zeng, S., Xie, X., & Tam, C. (2010). Relationship between cooperation networks and innovation performance of SMEs. *Technovation*, *30*(3), 181-194.

