Supernetworks: An Introduction to the Concept and its Applications with a Specific Focus on Knowledge Supernetworks

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Main Description

This paper discusses the concept of "Supernetworks" and its applications. It identifies challenges and new opportunities surrounding their understanding and management. It especially focuses on the new application of knowledge supernetworks.

We first present a short overview of the role that networks play in our modern societies and economies. We then introduce "Supernetworks" as a tool for the modelling, analysis, and solution of decision-making problems in the Information Age. We describe two applications of supernetworks comprised of economic as well as social networks. We, subsequently, turn to dynamic knowledge organizations. We demonstrate how the supernetwork framework can also be utilized to model abstract decision-making in this context. The model allows for multicriteria decision-making as well as the determination of the optimal transformation/production processes of the knowledge products through resource allocation. We illustrate how distinct knowledge organizations including news organizations and intelligence agencies can be captured within this framework.

Short Description

This paper discusses the concept of "Supernetworks" focusing especially on the new application of "Knowledge Supernetworks".

Keywords

Knowledge production
Networks
Supernetworks
Social and economic networks
Multicriteria decision-making
Optimization
Knowledge organizations

1. Introduction

Networks in many different forms play an important role in our lives. Transportation networks enable us to move people and goods. Their smooth functioning is essential for the well-being of our economies and societies. Due to their importance, traffic network equilibrium problems have been rigorously studied in the 19th and 20th century dating back to Kohl (1841), Pigou (1920), Knight (1924), and the seminal book by Beckmann, McGuire, and Winsten (1956). The study of transportation networks continues to be a topic of avid interest. For an overview of some of the fundamental contributions to transportation network modelling and analysis, see Boyce, Mahmassani, and Nagurney (2005).

As the methods in transportation research have become more and more refined, researchers and practitioners have realized the applicability of such network models and related mathematical and computational tools to many other fields. Among such applications that have directly benefited from transportation-based network research are: supply chain networks (cf. Nagurney, Dong, and Zhang (2002), Nagurney, Loo, Dong, and Zhang (2002), and Nagurney, Cruz, and Matsypura (2003)), financial networks (Nagurney and Siokos (1997), Nagurney and Ke (2001, 2003), Nagurney and Cruz (2003)), environmental networks (see, e.g., Nagurney and Toyasaki (2003)), and even energy/power networks (Nagurney and Matsypura (2004)). Indeed, the rigorous mathematical network approach that allows for the computation of optimal flows of goods and prices has proven to be a valuable addition to such areas as: logistics, economics, finance, and energy.

Recently, network models have been further developed to create what we term "Supernetworks". Supernetworks depict how flows and prices evolve on two, three or more networks that are "connected" and how the flows on the different networks interact. Supernetworks can be multilevel as in the case of certain supply chain networks or multitiered as in the case of financial networks with intermediation. Decision-makers on supernetworks may be faced with multiple criteria and have the ability to weight them according to their preferences.

A variety of applications of supernetworks have been identified; see, for example, Nagurney, Ke, Cruz, Hancock, and Southworth (2002), Wakolbinger and Nagurney (2004), Nagurney, Wakolbinger, and Zhao (2004), Cruz, Nagurney, and Wakolbinger (2004), and Nagurney, Cruz, and Wakolbinger (2004). Among them is the application of *Knowledge Supernetworks* (Nagurney and Dong (2005)). Knowledge supernetworks allow for the formalization of the production processes of knowledge products. They enable decision-makers to optimize their resource allocations by taking several criteria, for example, costs, risk, and the timeliness of the different available production processes into consideration. They have the potential to specifically consider the differences between the production processes associated with knowledge production as opposed to the production processes of physical goods.

In this paper, we give an overview of some of the work that has been done in the development and application of the supernetwork concept to-date and discuss where further extensions can prove to be valuable. The goal of this paper is to introduce the reader to the area of supernetworks, in general, and to knowledge supernetworks, in particular. For details of the models, we refer the reader to the different cited papers.

This paper is organized as follows. In Section 2, we provide an overview of networks, their role in our societies and economies, and their distinct features. In Section 3, we turn to the concept of "Supernetworks" as a tool for the modelling, analysis, and solution of decision-making problems in the Information Age. In Section 4, we first describe two applications of supernetworks in the integration of economic and social networks. We then consider dynamic knowledge organizations and demonstrate how the supernetwork framework can also be utilized to abstract decision-making in this context and to allow for multicriteria decision-making as well as the determination of the optimal production of the knowledge products through the optimal allocation of resources. Finally, in Section 5, we present our conclusions and suggestions for future research.

2. The Role of Networks in Our Societies and Economies

In this section, we describe the importance of networks in our societies and economies. As discussed in Nagurney (2004), networks, especially, transportation and communication networks, have played critical roles throughout history. We would like to illustrate four distinctive features of today's networks: their large-scale nature and complexity, increasing congestion, as well as interactions between the networks themselves (cf. Nagurney (2004)).

Nowadays, networks in different forms build the backbones of our societies and economies. These networks include physical networks like transportation, logistical, communication, energy and power networks, as well as more abstract networks like economic, financial, environmental, social, and knowledge networks.

Recent terrorist attacks and power blackouts impressively and dramatically demonstrated the vulnerability of our societies and economies when networks stop functioning. This is due to *our dependence* on different network systems and *their interdependence*. Furthermore, these events have also shown how immense many networks are and that national borders seldom restrict them in their impacts.

With increasing size and utilization of networks, congestion is becoming a more and more important problem. The problem of congestion was originally only considered in transportation networks where it leads to an incredible amount of loss of productivity. It is becoming increasingly apparent that in many other networks, for example, even in the Internet, congestion has become a major problem, as well. Tools from transportation are already proving to be valuable in the context of Internet congestion modelling and management (see, e.g., Boyce, Mahmassani, and Nagurney (2005) and the references therein). Indeed, tools from transportation provide not only the graph theoretic structures of networks in the form of nodes, connecting links, and paths, but also the impact of flows on associated costs (times) and the selection of the optimal paths by the users of the networks. Moreover, in such networks, decentralized decision-making in the case of users selecting their optimal routes of travel (as opposed to centralized decision-making) tends to be the principal behavioral concept (cf. also Wardrop (1952) and Nagurney (1999)).

Because of the strong interactions between many networks the growth of one network usually influences other networks as well. This can be observed in the case of the Internet. The Internet changed the way in which many people work, shop, conduct their financial transactions, and communicate with one another. Hence, the Internet has transformed many other networks, and has affected such networks as supply chain and financial networks, through the introduction of electronic commerce and electronic finance, respectively. Moreover, it has impacted the usage of transportation networks. The fast growth of the Internet has attracted a lot of attention, but its relationships with and impacts on other networks, including social networks, has only recently been receiving adequate research attention (cf. Nagurney and Dong (2002)).

3. The Concept of Supernetworks

In a world influenced by ever growing networks, new paradigms are necessary for decision-making. We believe that the concept of supernetworks is sufficiently general and yet elegantly compact to formalize such decision-making. ""Super" networks are networks that are "above and beyond" existing networks, which consist of nodes, links, and flows, with nodes corresponding [to] the locations in space, links to connections in the form of roads, cables, etc., and flows to vehicles, data, etc. Supernetworks are conceptual in scope, graphical in perspective, and, with the accompanying theory, predictive in nature." (Nagurney and Dong (2002), p. xiv).

The supernetwork framework provides us with tools to study interrelated networks. It allows for the application of efficient algorithms for computation, and it provides visual aids to see the dynamic changes. Tools that are applied in the network framework include: optimization theory, game theory, variational inequality theory, projected dynamical systems theory, and network visualization tools.

Supernetworks enable the formulation of a plethora of models of numerous economic situations. The supernetwork models are mathematical representations of the behavior of distinct multicriteria decision-makers. The decision-makers can weight their individual criteria and optimize their behavior accordingly. The supernetwork models depict the interaction of the distinct decision-makers and the resulting flows and prices. In the models that we present, we take the synthetic approach promulgated by Nagurney and Dong (2002). Figure 1 shows the conceptualization of a supernetwork. This conceptualization especially emphasizes the interdependence of distinct network systems.

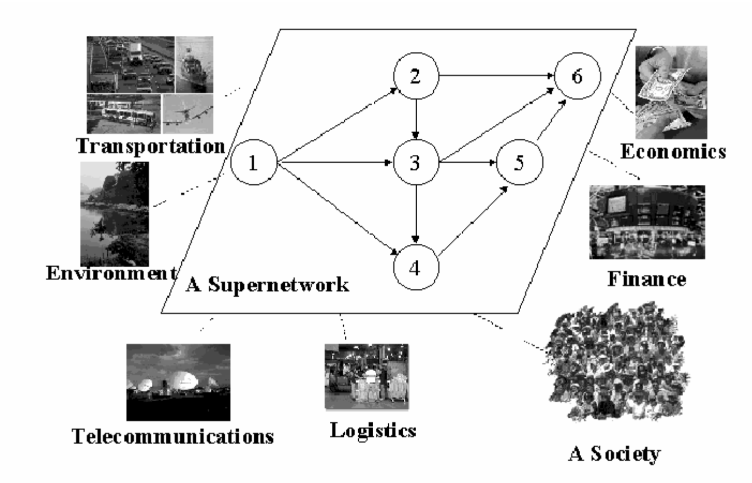

Figure 1
Conceptualization of a Supernetwork

4. Applications of the Supernetwork Concept

Supernetworks have a wide range of applications and only a small part of those applications has been explored thus far. Some specific applications of supernetworks are: supernetworks consisting of social networks interacting with supply chain networks, supernetworks consisting of social networks interacting with financial networks, and knowledge supernetworks. We now give a short introduction to these three applications.

4.1 Supernetworks Integrating Social Networks and Economic Networks

Social networks play an important role in many economic transactions. A social network is typically defined as a set of actors, that is, decision-makers, that may have relationships with one another. Actors are depicted as nodes and relationships as links. Networks can have few or many actors, and one or more kinds of relations between pairs of actors.

As it is acknowledged by an increasing number of researchers nowadays, it is not so much what you know but whom you know that determines the success of many economic transactions. The importance of relationships in economic transactions is obvious in many everyday situations. Still more research is necessary to quantifiably determine their influence. So far, the role of relationships in economic actions has been studied in the field of sociology, specifically, through embeddedness theory (cf. Granovetter (1985) and Uzzi (1996), among others), in economics (cf. Williamson (1983), Joskow (1988), Crawford (1990), Vickers and Waterson (1991), and Muthoo (1998)) as well as in marketing, specifically, in the context of relationship marketing (cf. Ganesan (1994) and Bagozzi (1995)). Empirical studies (cf. Dyer (2000) and Spekman and Davis (2004)) as well as case studies (cf. Mörch and Persson (1999)) have highlighted the importance of relationships in business transactions.

A strong strand of literature is dealing with the influence of relationships in financial transactions (see, e.g., Uzzi (1998) and Burt (2000)), especially the influence of relationships on lending, the influence of relationships on micro-financing, and in the realtor sector (see, e.g., Nagurney, Cruz, and Wakolbinger (2004) and Cruz, Nagurney, and Wakolbinger (2004) and the references therein).

In many economic and, of course, business transactions, the existence of a superior network of relationships can be a strong competitive advantage. Hence, it is important for organizations, including companies, to clearly define their goals and to strategically plan their relationship network accordingly. Certainly, relationship networks cannot be planned and set up like transportation networks. However, in a professional (and economic) context, relationships are certainly too important to be left to the capriciousness of coincidence. Resources should be strategically allocated to support or create certain important relationships with other main decision-makers, including customers.

This problem is well-suited to be modeled in the supernetwork framework. This framework captures the different interacting networks in one model. It allows one to compute optimal solutions under different scenarios and to test how the equilibrium will change when certain cost and benefit functions are changed or agents/decision-makers in the network are added or removed. The supernetwork framework, hence, clearly has the potential to help decision-makers understand the interactions of social networks and economic networks. Moreover, it allows for numerous sensitivity analysis exercises to be conducted with the effects of various changes being measured in a quantifiable manner.

Two fundamental supernetwork models that integrate social networks with economic networks have been developed thus far. The first paper, by Wakolbinger and Nagurney (2004), describes a supernetwork that integrates social networks and supply chain networks. The second paper, co-authored by Nagurney, Wakolbinger, and Zhao (2004) proposes a supernetwork model consisting of a social network and a financial network. Both supernetworks consist of three tiers of decision-makers: the manufacturers of products, the intermediaries, and the consumers in the first case (see Figure 2), and the sources of financial funds, the intermediaries, and the uses of funds (the demand markets) in the second case.

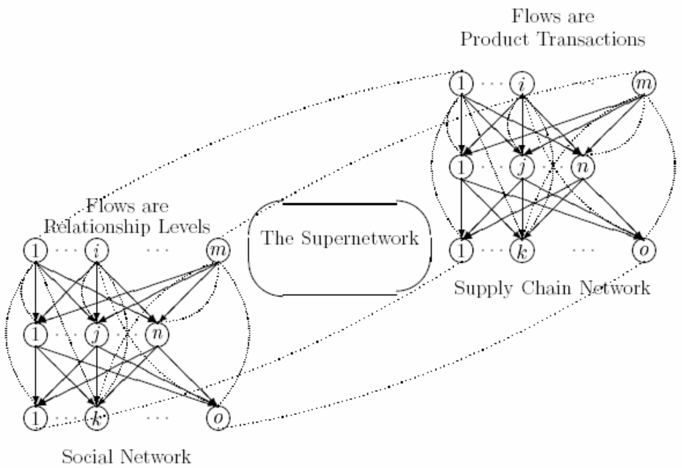

Figure 2
The Multilevel Supernetwork Structure of the Integrated Supply Chain / Social Network System (cf. Wakolbinger and Nagurney (2004))

The agents/decision-makers in the different tiers are multicriteria decision-makers. They can decide about the relationship levels that they want to establish with agents/decision-makers in other tiers of the network as well as the amount of products/financial products that they want to trade. Relationship levels can take on a value from 0 to 1 where 0 means no relationship while 1 stands for the highest possible relationship. Besides caring about maximizing profits and minimizing risk, decision-makers are also concerned about maximizing relationship value. The relationship value is a function of the relationship levels that the decision-makers establish with decision-makers in the other tiers of the network. Establishing relationship levels incurs some costs. Decision-makers have to spend money, for example, in form of presents or time, in order to establish relationships. Increasing relationship levels influence transactional uncertainty and transaction costs. They also have some additional value for the decision-makers. We call this additional value the *relationship value*. Hence, the decision-makers try to find the optimal combination of transactions with the agents/decision-makers in the other tiers of the network as well as the optimal combination of relationship levels. Economic transactions as well as relationship levels influence each other. The solution of the supernetwork model yields the dynamic co-evolution of the flows on the social and the economic networks as well as the associated prices.

Recently, in Nagurney, Cruz, and Wakolbinger (2004) and Cruz, Nagurney, and Wakolbinger (2004), these models have been extended to an international setting. Please see Figure 3 for a representation of the multilevel supernetwork structure of the integrated global supply chain / social network system. For details of the model, a literature overview, and an in depth description of the derivation of the basic concepts, see Cruz, Nagurney, and Wakolbinger (2004).

In the future, further developments of the models that focus more strongly on the special characteristics of social networks can be expected. Furthermore, future models will also explicitly consider benefits and drawbacks of emerging network structure.

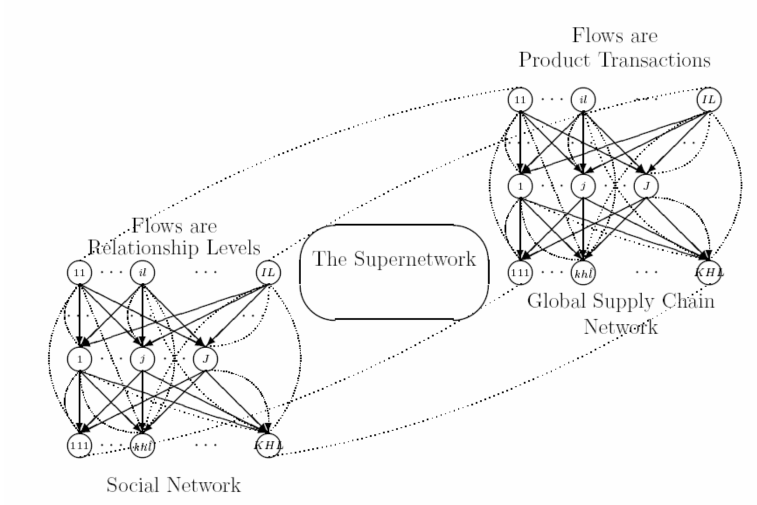

Figure 3
The Multilevel Supernetwork Structure of the Integrated Global Supply Chain / Social Network System (cf. Cruz, Nagurney, and Wakolbinger (2004))

4.2. Using Supernetworks for the Formalization of Knowledge Production

Knowledge production and dissemination is playing a role of fundamental importance in our world today. At a time when competition is becoming fiercer and many organizations, including companies, have to compete on a global scale, superior knowledge and its application are some of the determining factors for success. Many knowledge organizations, such as: news organizations, financial institutions, and intelligence agencies are in the "business" of producing knowledge products. In order to be competitive and to achieve their desired goals, such organizations have to determine how to best use their resources to most efficiently produce the knowledge products.

Various researchers have developed models to represent knowledge production (cf. Karlqvist and Lundqvist (1972), Andersson and Karlqvist (1976), Batten, Kobayashi, and Andersson (1989), Beckmann (1993, 1994), Kobayashi (1995), and Nagurney (1999)). These researchers have coincidentally also contributed to transportation research.

Nagurney and Dong (2005) developed a knowledge supernetwork model. This model is able to incorporate various related elements into one structure and view the problem in a systematic way. It can support decision-makers that try to determine the optimal allocation of resources. It can schedule the activities by capturing the alternatives available in a graphical format and by providing the optimal allocation of activities as well as resources, their dynamic development as well as possible alternatives and their related benefits and costs.

Knowledge production in the context of that paper, which we also take on here, is partly corresponding to the development of core capabilities in Ciborra and Andreu (2001). It can be described as a process "by which standard resources, which are available in open markets [...] are used and combined within the organizational context of a firm in order to produce" (Ciborra and Andreu (2001), p. 74) explicit knowledge goods that are of measurable value to certain target customers. Examples of knowledge goods are: news segments in the case of a news organization or pages of reports/studies in the case of an intelligence agency. The knowledge production processes are influenced by various factors inside as well as outside the organization. Decision-makers who try to optimize knowledge production are faced with a variety of challenges. These challenges include, but are not limited to, how to allocate the available resources efficiently and how to quickly respond to their customers' needs. In order to optimize their resource allocations amongst the available production processes, the use of information tools represents a valuable aid.

In the supernetwork model (for details, see Nagurney and Dong (2005)), the different possible ways to produce a knowledge product are represented by the different paths that consist of different links that are available. Those links may include: information processing links, telecommunication and/or transportation links, interface links, consolidation links, etc. The decision-makers in the network are multicriteria decision-makers that try to minimize total cost, risk, and time. They put a weight to each of these criteria depending on the importance that they assign to it. Using a link incurs some specific costs as well as specific risk and time. By being aware of these costs the decision-maker can optimize the production processes associated with the knowledge product. This model was developed for fixed as well as for elastic demand situations. Applications of this model that were identified by Nagurney and Dong (2005) are: the application to a news organization, to multinational research corporations, to global financial institutions, as well as to intelligence agencies. For a graphical representation of a simple knowledge network with multiple products see Figure 4.

Further studies in the field of knowledge supernetworks will certainly be necessary to more thoroughly understand the mechanisms that are present in this process. Suggested future directions for research include: the incorporation of competition into the framework, in which several knowledge organizations may share a subset of links, focusing more strongly on the special features of knowledge production, for example, by introducing uncertainty into the framework and by considering cultural aspects, and conducting empirical tests to validate the model.

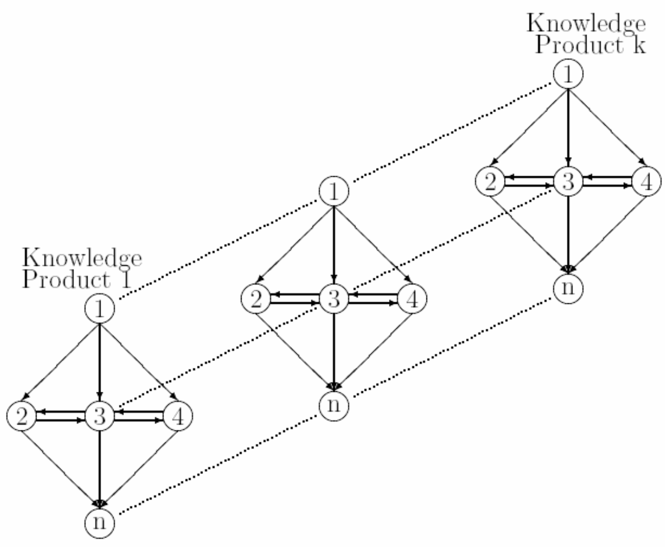

Figure 4
Example of a Knowledge Supernetwork (cf. Nagurney and Dong (2005))

5. Summary and Conclusions

In this paper, we overviewed the concept of supernetworks. We described two applications of supernetworks consisting of integrated social and economic networks. Furthermore, we discussed applications of a knowledge supernetwork model to knowledge organizations. Through these examples, we have attempted to demonstrate the power of the supernetwork framework which is determined by its ability to: incorporate various networks into one framework, view problems in a systematic way, incorporate multi-criteria into the decision-making process, provide tools to study interrelated networks, allow applying efficient algorithms for computation, and provide visual aids to see the dynamic changes. The applications that have been developed thus far only constitute a beginning of this line of research and we hope that this paper will further encourage researchers and practitioners to use and apply this framework and its associated tools in many different areas. In addition, we note that actual empirical studies to validate results from the theoretical models would be especially beneficial and this is part of our ongoing research agenda.

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