

## **Networks: Contribution to the Encyclopedia of Science, Technology, and Ethics**

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Throughout history, networks have provided the foundation and the infrastructure for humans to conduct their wide-ranging economic and social activities. Well-known physical networks in which nodes correspond to locations in space and links to appropriate connections with associated flows include transportation and communication networks. Transportation networks provide us with the means of crossing physical distance in order to conduct our business transactions and to visit colleagues, clients, friends, and family members as well as to explore new areas and to expand our horizons. Transportation networks have evolved over the centuries through advances in science and technology and come in a myriad of forms: road, rail, air, or waterway with a variety of associated modes of travel. Communication networks, in turn, allow us to communicate not only within our communities but across regions and national boundaries. They, through such innovations as the Internet, have transformed the manner in which we live, work, and conduct our business today. Communication networks enable the transmission of voice, data, information, and/or video and today may involve telephones, computers, as well as satellites and microwaves. Energy networks, on the other hand, provide the necessary fuel for many transportation and communication network transactions to take place.

In addition, more abstract networks such as financial networks, a variety of logistical networks, notably, supply chains, as well as knowledge and social networks, which are heavily based on communication networks, are playing new and not completely understood roles in today's societies and economies. Their reliability, efficiency, and accessibility enhance production and distribution, the exchange of information and knowledge, and add to the diversity and richness of goods and services. At the same time, the structure of such networks and the connectivity provided by them may yield advantages for particular individuals and organizations.

Organizations today, be they local, regional, national, or global in scope and as diverse as businesses, educational institutions, or governments, are highly dependent on networks, which are becoming increasingly interrelated. Indeed, individuals may now be able to conduct their financial transactions electronically and to shop globally from their places of employment and have the products delivered to the desired destinations. They may also, in certain circumstances, be able to work from home or another chosen location with deep and serious questions arising concerning the management of the underlying networks, their utilization and availability, as well as the auxiliary ethical significance of the network designs, accessibility, and usage.

The topic of networks and network management dates to ancient times with such classical examples including the publicly provided Roman road network and the time

of day chariot policy, whereby chariots were banned from the ancient city of Rome during particular times of the day (cf. Nagurney (2000)). The topic of networks as a subject of scientific inquiry originates in the paper by Euler (1736), which is credited with being the earliest paper on graph theory, where a graph in this context is meant an abstract or mathematical representation of a system by its depiction in terms of vertices (nodes) and edges (or arcs) connecting various pairs of vertices. Interestingly, not long thereafter, Quesnay (1758), in his **Tableau Economique**, conceptualized the circular flow of an economy as a network. Monge, who had worked under Napoleon Bonaparte in providing the infrastructure support for his army, published what is probably the first paper on the transportation network model in 1781. Much later, and following the first book on graph theory by Konig in 1936, the economists Kantorovich (1939), Hitchcock (1941), and Koopmans (1947) considered the network flow problem associated with the classical transportation problem. The study of network flows, primarily in a transportation context, hence, preceded the development of even optimization theory and such elegant algorithmic techniques as the simplex method (cf. Dantzig (1948)).

Indeed, the emergence and evolution of a plethora of physical networks over space and time, coupled with the realization of the importance of more abstract networks, and the effects of human decision-making on networks through their utilization and management has given rise to the development of rich and powerful theories that are rigorous, scientific, and network-based. The novelty of networks lies in that they are pervasive and fundamental and provide the fabric for the connectivity of our societies and economies. At the same time, methodologically, network theory has developed into a powerful and dynamic medium for abstracting complex network-based problems. Indeed, many of today's networks (including the Internet) are characterized by a large-scale nature, complexity of interconnections and interrelationships, congestion, and distinct behavior of the users of the networks, which may result in paradoxical phenomena such as the Braess paradox (1968), in which the addition of a new road in a transportation network (or a link in a communications network such as the Internet (see Korilis, Lazar, and Orda (1999)) makes all the users of the network worse-off. Methodologies for the formulation and analysis of network systems, hence, are of wide practical significance (cf. Ahuja, Magnanti, and Orlin (1993), Nagurney (1999), and Nagurney and Dong (2002)).

Today, it is possible, through advances in scientific models, theories, and computational tools to predict optimal routes on networks from different origins to destinations both from a system-optimized perspective, in which there is a central controller of the network flows, as well as from a user-optimized one, in which users of the network select their optimal routes in what may be viewed as a selfish manner (cf. Beckmann, McGuire, and Winsten (1956), Dafermos and Sparrow (1969), and Nagurney (1999), and Nagurney and Dong (2002)). In addition, it is possible to optimize financial portfolios from a network perspective (cf. Nagurney and Siokos (1997) and Nagurney (2003), to predict the profit-maximizing production and shipment patterns between tiers of network decision-makers (cf. Nagurney and Dong (2002)), and to even determine information flows in an organization (see Wu et al. (2003) and the references therein).

Nevertheless, there are many questions of ethical significance concerning networks, their operation and management, as well as accessibility, and usage, which we now highlight.

## **Accessibility and Ethical Issues**

In this segment, we focus first on transportation networks and then on communication networks. The first aspect of accessibility concerns the design of the network itself. The number of nodes and the number of links connecting the nodes determine the network topology whereas the quality of the links affects the ultimate accessibility and usage. For example, well-built roads will support travel and trade whereas an impoverished transportation network infrastructure can seriously impede development and growth. At the same time, the availability of alternative modes of transportation may enhance employment since workers can reach their (possible) places of work. Similarly, those who cannot drive or who cannot afford car ownership may be able to avail themselves (if provided) of cost-appropriate transportation modes.

The interrelationships between networks in this context also have ethical implications. For example, it is now well-established (cf. Nagurney (2000) and the references therein) that transportation and, in particular, vehicular transportation on congested urban networks not only results in a loss of productivity but also has serious consequences for the environment due to emissions. Moreover, the emissions need not be local but can be *transported* over political boundaries. Hence, the choices made by an individual in terms of route/mode selection can affect (negatively) populations much further afield. Although there may be economic approaches to ameliorating some of these negative effects through, for example, tolls or pollution charges, there may be incentives put in place that appeal to humans' individual sense of ethics.

In terms of communication networks, notably, the Internet, the accessibility issue has received a great deal of attention especially from a variety of government organizations. Indeed, terms such as the *digital divide* have become part of the popular lexicon. In certain fields, such as science, in particular, the essentialness of accessibility to the Internet for research and information and knowledge dissemination is well-known (see, e.g., Alberts (2000) and Newman (2001)). Less-emphasized and as important is to increase the connectivity in less-developed and developing nations, who may not only have poor communication infrastructures but who may suffer from substandard energy networks, as well.

Not only do scientists benefit from accessibility to communication networks such as the Internet, but educational systems throughout the globe can only be enriched through reliable and efficient Internet connections.

## **Usage and Ethical Issues**

Increased access to interconnected networks also raises major questions concerning ethical issues. For example, given that information of individuals can be retrieved in seconds by anyone with the appropriate computer connections, there are serious questions concerning privacy of the information and the right of individuals to check the correctness of the data and information concerning themselves. Moreover, the regulation of the content of what is circulating on the Internet given its huge and immediate reach is a subject of both ethical and legal importance. In addition, such computer-based crimes as hacking and computer piracy are examples of illegal and

unethical usage of communication networks. Such activities can have serious financial as well as personal consequences (see, e.g., UNESCO (1997)).

The Internet, by helping to span the globe and fertilizing people's right to communicate, has given freedom to many voices. It has played a major role in social and economic transformations and has helped in the internationalization of trade, especially through electronic commerce and the globalization of the nations' economies. Freedom, however, must come with responsibility a sense of ethics, and solid judgment of the consequences of one's actions on others. Never has the subject of networks and ethics been more timely and relevant.

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