The dynamics of infrasystems. Lessons from history

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Abstract

The infra(structural)systems and the built environment in which we live today are the result of decisions and efforts long ago. It is this historic legacy that is the point of departure of this paper. This paper has a rather broad and general scope. First some characteristics of infrasystems are presented. The following section focuses on the dynamics of infrasystems, analysing the factors and mechanisms that have contributed to their development in the past. The third and last section is devoted to a discussion of what lessons we can learn from history about the possibilities for redirecting infrasystems in the future in a more sustainable direction.

Introduction

One of the most fundamental societal changes in the Western World in the past two centuries has been the introduction and expansion of a number of large technological systems for transportation, communication, energy and water supply, and sewage and garbage collection. A common characteristic of these systems is that they facilitate movements of different kinds; of people, goods and information. Furthermore, they provide services that are publicly accessible and which fulfil a basic function in society. I will use the term infrastructural systems, or shortly just infrasystems, to denote these systems.

Infrasystems were first built between and within cities, and they have contributed to a fast expansion and a radical reconfiguration of urban regions. The establishment of infrasystems has enabled an intensified exploitation of natural resources as well as a division of labour on a hitherto unknown scale. As a result many production systems that previously were of a local or regional scope have become global in scope. For everyday life, infrasystems have implied what could be called a "convenience revolution". Many of the most strenuous household tasks have been taken over by electric household appliances, tap water, and central heating. Furthermore, the car and the telephone have given many households a dramatic increase of mobility and reach. Until now, it is primarily in the industrialised world that infrasystems have had these effects. In the developing countries most infrasystems are only accessible to the relatively wealthy, but the poor are eager to attain them as well. An expansion of infrasystems in these countries will most probably have tremendous impacts in coming decades.

The success of infrasystems can be summarized in the words: cheap, convenient and reliable. However, it is this combination of advantages that is also the root of their environmental problems. Through the ease

and cheapness of their services, infrasystems have strong tendencies to encourage increasing consumption of scarce resources. It is literally like opening a tap of water; why bother about the amount of water you use when taking a shower when it is so easy, so pleasant and so cheap? Infrasystems have affected the environment in two ways: First, many of them have severe direct consequences for the environment. Just think of the emissions from motorcars, airplanes and power plants. Secondly, infrasystems have considerable indirect consequences for the environment. The increased capacity for mobility they have brought about has enabled many households to settle in relatively large dwellings in suburbs, and they have developed increasingly energy- and transport-intensive lifestyles.

The infrasystems and the built environment in which we live today are the result of decisions and efforts made decades and even centuries ago. Likewise, decisions and efforts we make to build and rebuild systems and structures will shape the material world for future generations. It is the strong historic legacy of infrasystems that is the point of departure of this paper. I believe that a prerequisite for redirecting infrasystems towards sustainability is an understanding of their developments in the past and of their influence on settlement patterns. The purpose of the paper is to contribute to such an understanding. The paper covers a very broad topic and is therefore of a rather general nature.[1] I try to highlight some patterns and mechanisms that I believe are particularly important, and for pedagogic reasons I use a number of examples as illustrations.

Characteristics of infrasystems

The concept "infrasystem" is used to denote a certain category of large technical systems, and the study of infrasystems partly falls within a research field that is called the Large Technical Systems approach (sometimes abbreviated LTS). A major impetus for the development of this field was a book published in 1983 by the American historian of technology, Thomas P. Hughes, entitled Networks of Power, which analyses the establishment and growth of electricity systems in the United States, Germany and Britain. Hughes regards electrical systems in a broad sense, as socio-technical systems, including not only technical components, but also the people and organisations that design, build and operate these components, as well as the legal and economic frameworks for these activities (Hughes 1983). Hughes' book inspired many other scholars, and since the mid 1980s large technical systems have become a field of research, attracting a growing number of historians and social scientists (see for example Andersson-Skog & Krantz 1999; Blomkvist & Kaijser 1998; Braun & Joerges 1994; Coutard 1999; La Porte 1991; Mayntz & Hughes 1988; Summerton 1994; Tarr & Dupuy 1988).

A common characteristic of infrasystems is that they facilitate movements of different kinds. They can be described as consisting partly of a network of links (like rails) and nodes (stations), partly of a flow passing through this network (trains). Distributive systems, like electricity, water and television, have a unidirectional flow from one or several central nodes to a large number of users. Accumulative systems, like sewer and garbage collection, have a reverse unidirectional flow, from many users to one or several central nodes. Communicative systems, like telecom, post and transport systems, provide a two-way flow (Jonsson 2000).

The character of the networks varies greatly between different systems. Some systems presuppose the construction of specific networks consisting of for example electric lines, water pipes and rails, which are built solely for the particular system. Other systems are largely based on natural "networks" like water, air or ether in conjunction with harbours, airports, transmitters and receivers. And still others, like the post

system or the internet, use existing transport or communication networks in combination with terminals, post-boxes, servers and the like. Another categorization of networks can be made in terms of their geographical shape, and in particular the points of access for the users. Point-shaped networks are accessible to the users only in a limited number of exclusive nodes, i.e. airports, stations and harbours. Line-shaped networks are accessible along their links where nodes can easily be arranged, i.e. telephone and electricity lines. Surface-shaped networks i.e. radio, TV and mobile phones, are accessible in every point within a distribution area (Kaijser 1994).

One fundamental aspect of an infrasystem is its reliability. As they fulfil basic functions in society, which are necessary for many different kinds of activities, interruptions or breakdowns can have far reaching consequences. The American sociologist Charles Perrow makes a useful distinction between tightly coupled and loosely coupled systems. A tightly coupled system is more vulnerable as a disturbance in one component rapidly spreads to other parts, while a loosely coupled system has more redundancy. To obtain a sufficient degree of reliability in a tightly coupled system, it has often been necessary to have one system operator co-ordinating the flows. In a loosely coupled system, like road traffic, the establishment – and enforcement – of common rules and norms can often result in an acceptable reliability (Perrow 1984).

Another important aspect of infrasystems, not least in relation to the issue of sustainability, is what economists call their external effects, which can be both positive and negative. If for example a large airport is built outside a city, this will normally give considerable positive economic effects for the whole city region, attracting new businesses etc. A large part of these economic effects do not result in profits for the airport or airline companies, and are therefore called "external" effects. But an airport will also have considerable negative effects, not least in the form of noise disturbance for people living in its vicinity. Also these effects are external in the sense that they often do not cause any costs for the airport company. Thus the establishment and expansion of infrasystems will have different kinds of effects for different actor categories. And these effects are not distributed at random; they reflect political and economical inequalities in a society. In general, the wealthy and politically influential citizens get more of the positive benefits, while the poor get more of the negative ones.

The dynamics of infrasystems

In the introduction I argued that the success of infrasystems can be summarised in the words: cheap, convenient and reliable. This is, to be sure, an observation in hindsight. When efforts have been made in the past to develop and establish new infrasystems, there has always been a major uncertainty whether the system would be viable or not. Most historical research has focused on the successful attempts, but it should be stressed that uncounted attempts have actually failed. In this section I will first outline some characteristics of three phases in the development of individual infrasystems, and then briefly discuss the interplay between infrasystems.

Establishment

It is well known that many infrasystems are based on a radical technical innovation, connected with inventors such as Alexander Bell, Thomas Edison, Guglielmo Marconi and many others. However, the establishment of the system on a first market generally requires a huge investment, and at this early stage it is mostly very difficult to assess the future demand for the services of the system. The establishment phase is therefore characterised by a very high uncertainty. A crucial problem is how to find mechanisms for

overcoming this uncertainty. A common feature of many systems is that a fundamental institutional innovation was made in an early stage, enabling a common use of the new system by many different groups, thereby diminishing the uncertainty. (I use the concept institutional innovation in a rather wide sense, referring to a change in the relation between provider and user of a service often accompanied by a change in the nature of the service.) I will shortly outline the introduction of gas lighting to illustrate this process.

In the late 18th century a number of engineers and inventors tried to develop new technologies for lighting. At the turn of the century a Frenchman, Phillipe Lebon, and an Englishman, William Murdoch independently designed simple gasworks, in which gas could be produced out of coal, peat and wood, which were much cheaper than the dominant lights sources at this time, tallow and whale oil. However, a gasworks represented a considerable investment in retorts and pipes. It is therefore not surprising that the first commercial use of gas lighting was in factories. For the owners of large factories, needing to light huge buildings, gas lighting implied a significant reduction of their lighting costs. However, for other categories of light consumers, the high capital costs of a gasworks represented an insuperable obstacle. Thus the market for the new lighting technology seemed to be restricted to large factories with a high demand for lighting.

It is at this point of time that a radical new idea was developed for how to overcome this obstacle by Friedrich Albert Winzer, a German entrepreneur living in London. His idea was to sell gas, not gasworks. His goal was to distribute the investment cost for a gasworks among many users, thereby reducing the "entry fee" for each of them. He developed a plan to establish a joint-stock company that would build a big gas-producing plant in the middle of London, and a whole network of pipelines under the streets. This would enable the company to sell gas at a relatively low price to a large number of subscribers and also to supply gas for street lighting. His ideas met fierce opposition not least from people with interests in the supply of existing means for lighting, whale oil and tallow, but after a number of years he succeeded to form an alliance of actors that was sufficiently strong, and in 1812 Parliament gave permission to found the "The Gas Light and Coke Company". Two years later the company began selling gas and within ten years gas lighting was used by many thousand of subscribers in shops, restaurants, workshops, offices and households as well as for street lighting. Many other cities in Britain and on the continent followed London's example in the next decades (Elton 1958, Kaijser 1986).

The idea of selling gas instead of gasworks led to an institutional innovation of fundamental importance. It was by finding a way for a communal use of the expensive gas producing plants that gas lighting became affordable for many more. In short, gasworks became an infrasystem, and the introduction of gas lighting led to a radical change of urban life in the course of the 19th century. A similar story - of a communal use of a system by many different kinds of groups - can be told for a number of infrasystems. In the railway system a key innovation was to provide not just a rail (like the canals did) but to offer transport, both of passengers and of goods (Lilley1973).[2] In the case of urban water systems a prerequisite for mustering the necessary capital was that the water could be used for several purposes; in households, in factories and for fire fighting (Hallström 2002).

My point is thus, that the crucial problem in the establishment phase of an infrasystem is uncertainty, and that the establishment of a new system has generally involved an institutional innovation, which has enabled communal use of heavy investments making a new service affordable for many different categories of people. Moreover, this innovation has to be supported by an alliance of powerful actors.

When one city or region has been able to establish a successful infrasystem, many others will soon want to follow its example. However, each city, region or country will try to adapt the institutional set-up of the infrasystem to its own political and socio-economical conditions.

The institutional shaping of an infrasystem can be seen as the result of an encounter between technology and society. The technical subsystem imposes certain demands on, for example, the degree of coordination and control, but these demands can be met within a more or less broad spectrum of organisational and legal frameworks. Which of these possible frameworks that is imposed depends on social and cultural traditions and the relative power of different interest groups in a country or a city. The institutional frameworks shaped for the first infrasystems in a city or a country have often served as a model when infrasystems have been established later on. This "institutional transfer" has led to the emergence of specific national institutional regimes for infrasystems. In some countries public authorities have taken a very active role in the building and operating of infrasystems, while in other countries public authorities have primarily had a regulatory role, trying to avoid that system operators make an abuse of a monopoly situation (Dobbin 1994; Kaijser 1999).

Expansion

Once an infrasystem has been established and reached a first major market an entirely new situation develops. The revenues from sales provide an economic base and the experiences of building and operating the system often lead to further technical improvements. This shapes the prerequisites for the expansion of infrasystems, either by way of new customers wanting to use its services (outer expansion) or through an increase of the consumption by old customers (inner expansion). There are generally strong economic and social forces for expansion.

Let us first look at the economic forces. The marginal costs for providing additional units of service have usually decreased in expanding systems, due to economies of scale and economies of scope. The economies of scale arose primarily on the "production side". For example, the production cost for a unit of gas or electricity decreased when the size of the generating plants increased (Hirsh 1989). Likewise, the cost per passenger or unit of goods usually decreased as the size of ships, trains and airplanes increased. Falling costs enabled lower prices, which raised demand and spurred further increase of scale etc. The economies of scope arose primarily on the consumption side. For example, gas was first used mainly for gas lighting, which implied that most of the gas was used in the morning and in the evening. Huge gasometers were needed to store gas produced during the day. In the late 19th century gas was also introduced for cooking, water heating and for industrial processes and motors. These markets had a different demand pattern over time, and as a result a more even use of gas was achieved. Another way to phrase this is to say that the load factor of the system increased. A high load factor implied a better utilisation of the huge capital costs of the system, and thereby lower costs per unit of service (Hughes 1983).

In infrasystems providing communicative services there is also another kind of economic force stimulating expansion that I would like to call economies of reach.[3] The economies of reach have to do with the extent of the network, and thereby the number of people or places that can be reached by using it. It implies that the growth of a system can be an important quality in itself. In the telephone system, for example, the connection of a new subscriber was not only rewarding to the new subscriber, but also to all the existing subscribers, which received an additional person to call (Helgesson 1999). Economies of reach

have also been of importance for the growth of transport systems. For example, the attractiveness of having a car increased as the network of roads grew and was improved. In many countries, powerful motorcar lobby organisations arose, which succeeded to persuade authorities to invest in the improvements of roads (Blomkvist 2000).

Besides the economic forces there have also been strong “social” forces for expansion. On a macro level expanding infrasystems acquired what Thomas P. Hughes calls momentum. Companies, which had invested much capital and other resources in a system, developed a strong interest in the further expansion of the system. Furthermore, there was a need for engineers with special skills, and these often had a common educational background. Such professional groups often formed tightly knit networks sharing the same values and with a similar views concerning the desired future direction of the system. They thus develop a common system culture, which in itself became a strong force for expansion (Hughes 1983).

On the micro level there have been parallel social processes. When a new infrasystem was established there was often a certain resistance towards it from potential customers. Besides the costs for joining the new system, their resistance was often based in a reluctance to change habits and routines, for example changing from cooking on a wood stove to cooking on gas stove. However, if their resistance was overcome, and they did change to the new system, they developed new skills and new habits making them dedicated followers of this system and reluctant to change to other ones, for example electric stoves (Hagberg 1986).

Thus, once an infrasystem was established on a first major market, strong forces for expansion arose, producing a spiral of growth. Economies of scale, scope and reach led to falling costs and decreasing prices of the services. This spurred the recruitment of new customers and the increase of consumption among the old ones, which led to a further decrease of costs etc. However, a fast expansion of a system was seldom a smooth process. Technical obstacles and difficulties often appeared, threatening to block the expansion. For example, increases of scale or distance have often been difficult to achieve. Thomas P. Hughes uses a military metaphor to describe this phenomenon. He talks about a “reverse salient” in an advancing front, which was a typical feature in the trench warfare during W.W.I. When such reverse salients emerged in the expansion of infrasystems, no resources were spared to try to overcome them. The best scientists and engineers available were engaged in these efforts, and radically new components, sub-systems or system-architectures were often the result, which in turn enabled a continued fast growth (Hughes 1983; Hughes 1992).

A fast expansion of an infrasystem, brought about by alliances of powerful actors, often resulted in considerable economic gains for many parties. However, in many cases the system also led to negative effects in the form of pollution and health problems affecting other parties. For example, the coal-fired gas-producing plants gave many workplaces and households access to a convenient energy source, but it also brought about severe health problems, in particular for the workers employed in the plants and for people living close by. Another example is the introduction of water closets a century ago, which improved the hygienic conditions for well-to-do urban households, but also contributed to the pollution of rivers and lakes, which in turn affected many other people. In the past such environmental and health problems have generally not become reverse salients in Hughes’ sense, as they have not been acute threats to the further expansion of the systems. And therefore they have not attracted the same kind of attention as the direct obstacles to growth.

Stagnation

Expansion processes do not go on forever. Sooner of later infrasystems reach a phase when growth rates diminish and a phase of stagnation commences. One factor contributing to stagnation has been a weakening of economic forces for expansion. Economies of scale have reached a saturation level in a number of systems. The maximum size of for example power plants, freight ships and aeroplanes has not increased since the 1970s. There has also been a saturation of demand for the services of many infrasystems. In many industrialised countries a growing part of economic activity was directed from material intensive towards more knowledge intensive products and systems in the last quarter of the 20th, and this was reflected in a much slower growth of the demand of energy, water and goods transport. In addition, more efficient end-use technologies have also contributed to a slower growth of demand.

When it comes to economies of reach, it is not uncommon that systems have even experienced a transformation into diseconomies of reach. In the case of road traffic in urban regions, additional cars have steadily increased the congestion on existing roads, and due to a scarcity of land it has been difficult to build additional roads. Thus the more cars, the longer it takes for each to reach its destiny, and this of course hampers the further expansion of car traffic. A similar process affects aviation systems in some densely populated regions like Europe.

There is one more factor, which has often played a crucial role in processes of stagnation and decline of infrasystems, namely competition from other systems providing similar services. (I will use the concept functional equivalents to denote two or more systems fulfilling the same function.) However, this is only one aspect of the interplay of infrasystems, and therefore it will be treated in the following section.

Interplay of systems

There have been two main kinds of interplay among infrasystems. First competition among systems being functional equivalents has been a major stimulus for technical and economical improvements of systems, but also a cause for decline. Competition between gas and electricity systems is a clear example. Gas systems were during most of the 19th century uncontested as providers of a high-quality energy source, which could be used for lighting, cooking, heating and mechanical power. However, the electric power systems established in the early 1880s provided an energy source, which could be used for exactly the same purposes. In fact, when Thomas Edison designed his first electricity system for lighting in the Wall Street district in Manhattan he had the existing gas systems as a model. As a consequence a fierce competition arose between the promoters of the two systems, first for the lighting market and later on for the motor market, the stove market and the heating market, stimulating technical improvements of both systems. For example, the struggle for the lighting market led to a dramatic increase in the efficiency of both gas lamps and electric lamps, but in the 1910s electric lighting had become superior and gas lighting declined. Particularly in countries with abundant hydropower resources (and thus cheap electricity), gas systems were pushed back also in the other markets and many of them were closed-down in the mid 20th century. However, with the introduction of natural gas, the position of the gas industry versus electricity has been strengthened anew (Kaijser 1993).

Similar processes of competition have taken place among transportation and communication systems. In the second half of the 19th century canals competed with railways and half a century later there was an intense struggle between railways and motorcars. Likewise the telegraph and the postal systems had to struggle with telephone system in the beginning of the 20th century. The older systems struggled very

hard to improve their efficiency, and while being pushed back in some markets they were sometimes able to keep their position in some market segment, in which they had special competitive advantages. Sometimes such a system has even been able to make a comeback. High-speed trains and electric tramways are two examples of this (Grübler 1990).

There is also another form of interplay among infrasystems. They often play a complementary role to each other achieving synergistic effects. One classical example is the building of telegraph lines along railway tracks. The telegraph made it possible to communicate between stations and this made it possible to increase train traffic considerably. At the same time the railway facilitated the building and maintenance of telegraph lines, and also provided a guaranteed market for telegraph traffic. Another example of system synergism is a co-generation plant, in which the heat losses from electricity generation are used for the heating of many houses via a so-called district heating system. The combined production of electricity and heat is much more efficient than a separate production of each, and this was often a major incentive to build district-heating systems (Summerton 1992; Hård & Olsson 1995). A third example is from the transportation sector. Transportation systems do not only compete. They often also need to co-operate because their networks have different coverage. However, an obstacle to such co-operation has been the high costs for trans-shipment. In the 1950s and 60s the container was introduced to facilitate the integration of different transportation systems, and thus to achieve synergistic effects (Egyedi 1996).

What can we learn from history?

"In sum it is difficult to change the direction of large electric power systems – and perhaps that of large socio-technical systems in general – but such systems are not autonomous. Those who seek to control and direct them must acknowledge the fact that systems are evolving cultural artefacts rather than isolated technologies. As cultural artefacts, they reflect the past as well as the present. Attempting to reform technology without systematically taking into account the shaping context and the intricacies of internal dynamics may well be futile. If only the technical components of systems are changed, they snap back into their earlier shape like charged particles in a strong electromagnetic field. The field must also be attended to: values may need to be changed, institutions reformed, or legislation recast. " (Hughes 1983)

This quotation is from the concluding paragraph of Thomas P. Hughes book Networks of power. Hughes here underlines what I think is the most important general lesson from history: Infra-systems are social constructions; they do not develop in some autonomous, uncontrollable way, even if it sometimes may seem so due to the "momentum" that many of them have acquired. It is possible to redirect systems, but this presupposes that an alliance of interests can be formed that is powerful and persistent, and whose actions are based on an understanding of the socio-technical nature of infrasystems. In this concluding section of the paper, I will try to draw some conclusions and lessons from history that may guide those that want to contribute to the redirection of infrasystems in a sustainable direction.

Infrasystems are socio-technical systems

A first lesson is that infrasystems are socio-technical systems, in which the institutional frameworks and the system culture are as important as the technical components. In the public debate, there is generally a lack of understanding of the importance of these "soft" parts of infrasystems and a strong belief in "technical fixes". However, a prerequisite for achieving lasting changes is that the system culture and the institutional conditions are altered. I have argued that the establishment of infrasystems has often been

dependent on a crucial institutional innovation, which made it possible to overcome the initial uncertainty by distributing the huge capital costs for building facilities and networks among many users. In fact, the communal use and the public accessibility (to all that are willing to pay for the services) is the very essence of infrasystems.

The institutional shaping of an infrasystem can be seen as the result of an encounter in the past between technology and society. For this reason the institutional frameworks for infrasystems have differed considerably both among systems and among countries and regions. The frameworks of infrasystems have often been rather stable over time, and they contain a heavy legacy. This makes it important to learn about their history. They were largely shaped long ago by people, which conceived a number of problems to be overcome and opportunities to grasp. It is also important to remember that they have often been shaped in societies that were not democratic, but in which a small elite had the political power and used it to promote their own ends. In general, these frameworks have primarily been shaped to facilitate the expansion of infrasystems, simply because the positive effects of the systems were much more obvious than the negative ones, in particularly for the wealthy. This urge for expansion is in many cases deeply imbedded in the system culture permeating the organisations owning and operating the systems.

When trying to redirect infrasystems in a sustainable direction, it is thus crucial to make changes in their institutional frameworks and in their system culture in such a way that strong incentives are created for finding solutions that are environmentally benign. There is almost always strong opposition within organisations towards changes of this kind. A prerequisite for accomplishing them is therefore that a broad alliance can be formed, including people from all spheres of society, including political parties, environmental organisations, industry, public authorities, trade unions and universities. There seem to be circumstances that can facilitate such changes in the coming years; it can be argued that we are at present in a formative phase. The reason is that rather far-reaching changes in the institutional frameworks of infrasystems have taken place in many countries in the past ten to fifteen years under the heading of "deregulation". The primary aim has been to increase the economic efficiency of infrasystems by stimulating competition among many system operators and by facilitating cross-border traffic. At the same time the importance of environmental considerations is being understood in ever, wider circles. These two processes may together provide a window of opportunity for implementing institutional changes, which will make environmental considerations imperative in the development and operation of infrasystems.

Dynamics of infrasystems

A second lesson pertains to the dynamics of infrasystems, and here one main message is that it is important to realize that infrasystems go through phases with different conditions. Policies for change have to take this into account.

For infrasystems in an early stage the major challenge is to overcome uncertainties and to find a first market where it can be established. In fact, most attempts to establish new infrasystems fail. The establishment of a new, environmentally benign system may therefore need substantial support from public authorities to overcome initial uncertainties.

When a system has been successfully established in a first market, it may reach a phase in which strong economic and social forces for expansion create a fast spiral of growth. The overriding concern for the system operators and politicians during such periods is generally to ensure an expansion of the system that is fast enough to meet the growing demand. Long-term effects of the systems on the environment and in

other aspects tend to become secondary, precisely in the period when most of the long-lasting hardware is installed.

A phase of fast expansion often brings about a system culture in which future growth is taken for granted, and it therefore often takes long time for the managers of infrasystems to anticipate a stagnation or decrease in demand of their services. This may lead to the creation of a substantial overcapacity, as has been the case for energy- and water supply systems in many industrialised countries in the past decades. Such an overcapacity diminishes incentives for efficient use of services.

Another important issue, in relation to the dynamics of infrasystems, is how environmental problems can be given a higher priority when developing new components or sub-systems. Particularly in the expansion phase of infrasystems obstacles or "reverse salients" have appeared threatening the further expansion. Typically such "reverse salients" have pertained to the increase in scale of components or sub-systems, and the incentives to overcome them have been very strong. A key question is then how the environmental effects of infrasystems can become "reverse salients", attracting the interest of leading engineers and scientists.

Since the 1970s, there has been a growing environmental movement in many industrialised countries, and this has spurred politicians to promote environmentally benign technologies, not least in energy and transportation systems. One policy has been to "put a price on the environment" by introducing taxes or fees on scarce resources or on pollution. This has certainly stimulated the development of system components, which are more resource-efficient or have lower emissions, but it has seldom led to the sense of urgency that is necessary to create a reverse salient. Another policy has been to introduce compulsory environmental standards or to forbid certain kinds of dangerous substances. These kinds of policies have been rather successful in some cases, for example diminishing the use of CFC-gases and introducing lead-free petrol. However, industrial interests have often been able to prevent or at least moderate such legislation. It is the latter kind of policy, if pursued in a consistent and determined way that has the potential to make "reverse salients" of environmental problems.

There is also another problem. Developing new environmentally benign technologies is not enough. They also have to be broadly adopted. The car industry illustrates this dilemma. While new cars are being developed with ever-lower fuel consumption and emissions, an increasing number of customers prefer to buy bigger and bigger cars (vans, jeeps, SUVs etc.) and they seem to be rather insensitive to costs.

Interplay among infrasystems

A third lesson is that interplay among infrasystems can be of crucial importance. On the one hand competition among systems fulfilling the same function has been a major factor in the development of many infrasystems both as a stimulus for technical and economical improvements and as a cause for decline. On the other hand infrasystems have often played a complementary role to each other producing synergistic effects, as illustrated by the railway and the telegraph. This kind of complementary interplay is increasing rapidly. In particular, modern information and communication technologies, ITC, are becoming more and more essential for the management and operation of all kinds of infrasystems. This development is double-edged. On the one hand it provides a potential for improving co-ordination within and among systems, not least in the transport sector. For example, most major freight companies have introduced new information systems in the past decade enabling a substantial increase in the load factor of

lorries. There is, however, another side to this coin. A growing interwovenness of infrasystems will also lead to an increasing complexity and vulnerability.

Another kind of interplay among systems is the joint use of networks. Building new networks or rebuilding existing ones is always very expensive, and in particular in dense urban areas.[4] This makes existing networks a very valuable asset, and they can play a crucial role for introducing new systems. For example, Internet services can be brought to a new customer in a number of ways: either by using existing telephone lines, electricity lines, TV-cables or radio transmission or by installing a new optic fibre.

In many other cases, access to existing networks will be contested. One example concerns the distribution of electro-magnetic frequencies, which can function as networks for many different kinds of systems. Broadcasting companies were among the first players on the scene, and they divided many of the most attractive frequency ranges among themselves from the 1920s and onwards. But in the past decades many new kind of systems have been developed which make claims on frequencies, and this has led to hard negotiations about reallocation of frequencies. Another example concerns urban roads and streets, which have been used by many different modes of transport in the past. At times there has been intense competition among systems for street space. In the mid 20th century this competition was aggravated by an increase in the number of cars, and in many cities streetcar systems were abandoned in order to give more room for cars and buses (Ekman 2003). Since then, cars have achieved a dominant and privileged position on the streets. This privileged position of the car will most probably be renegotiated in coming decades, in order to provide room for more environmentally benign and space efficient transport systems. However, the influential motorcar lobby organisations will probably fight hard to prevent such a development. In the past years they have strongly opposed the introduction of road pricing, which is probably the most effective way to achieve a more efficient use of scarce road space.

I hope that this paper may give some insights to those that want to redirect infrasystems in a sustainable direction. Let me repeat the main message: It is possible to redirect systems and it is important to do so, but it is difficult. It presupposes that an alliance of interests can be formed that is powerful and persistent, and whose actions are based on an understanding of the socio-technical nature of infrasystems.

Notes

[1] As the paper covers such a broad area, I have been restrictive when it comes to references. It is partly based on previous works by me alone and in co-operation with others, and in these works more extensive references can be found.

[2] The first public railway, built in 1825 between Stockton and Darlington in England, was organised like a canal, just offering a rail. This proved to be inefficient when traffic grew, and the second public railway built in 1830, between Manchester and Liverpool was therefore organised in a totally different way; it offered transport, not just a rail. In addition to building a railway, this company also bought wagons and locomotives and organised train traffic following elaborate timetables.

[3] The term that is usually used to denote this phenomena is "network externalities", but I think that the expression economies of reach give a better intuitive understanding of the phenomena.

[4] The huge cost of rebuilding existing networks is illustrated by the so-called ”Big Dig” in Boston. The replacement of an elevated motorway cutting right through the downtown with a tunnel of a few kilometers length will cost at least 20 billion USD.

References

Andersson-Skog, L. & Krantz, O. 1999. Institutions in the transport and communication industries. State and private actors in the making of institutional patterns, 1850-1990. Canton, Ma.

Blomkvist, P. & Kaijser, A. (eds.) 1998. Den konstruerade världen. Tekniska system i historiskt perspektiv. Stockholm.

Braun, I. & Joerges, B. (eds.) 1994. Technik ohne Grenzen. Frankfurt am Main.

Coutard, O. (ed.) 1999. Governing large technical systems. New York.

Dobbins, F. 1994. Forging Industrial Policy. The United States, Britain and France in the Railway Age. Cambridge, MA.

Egeydi, T. 1996. Standardisation of the container. The development of a gateway technology in the system of cargo transportation. Stockholm.

Ekman, T. 2003. Spår i vägen: Teknikval, politik & spårvägstrafik i Stockholm 1920-2002. Stockholm.

Elton, A. 1958. Gas for Light and Heat. In: Singer, C. (ed.) A History of Technology, Vol IV.

Grübler, A. 1990. The Rise and Fall of Infrastructures. Dynamics of Evolution and Technological Change in Transport. Heidelberg.

Hagberg, J.-E. 1986. Tekniken i kvinnornas händer. Hushållsarbete och hushållsteknik under tjugo- och trettiotalen. Malmö.

Hård, M. & Olsson, S.O. 1995. Enforced Marriage: How District Heating and Electricity Systems Have Been Combined. In: Kaijser, A. & Hedin, M. (eds.) Nordic Energy Systems: Historical Perspectives and Current Issues. Canton.

Helgesson, C.-F.1999. Making a natural monopoly. Stockholm.

Hirsh, R. 1989. Technology and Transformation in the American Electric Utility Industry. Cambridge.

Hughes, T.P 1992. The Dynamics of Technological Change: Salients, Critical Problems, and Industrial Revolutions. In: Dosi, G., Gianetti, R. & Toninelli, P.A. (Eds.) Technology and Enterprise in a Historical Perspective. Oxford.

Hughes, T.P. 1983. Networks of power. Electrification in Western Society 1880-1930. Baltimore.

Hughes, T.P. The evolution of large technical systems. In: Bijker, W., Hughes, T. & Pinch, T. (eds.), The social construction of technological systems. New directions in the sociology and history of technology (Cambridge, Ma), 51-56.

Jonsson, D. 2000. Sustainable Infrasystem Synergies – A Conceptual Framework. In: Journal of Urban Technology, Vol 7, Nr 3, 81-104.

Kaijser, A. 1986. Stadens ljus: Etableringen av de första svenska gasverken. Malmö.

Kaijser, A. 1993. Lighting and Cooking: Competing Energy Systems in Sweden, 1880-1960. In: Aspray, W. (ed.), Technological Competitiveness: Contemporary and Historical Perspectives on the Electrical, Electronics, and Computer Industries (Piscataway, NJ) 195-207.

Kaijser, A. 1994. I fädrens spår. Den svenska infrastrukturens historiska utveckling och framtidda utmaningar. Stockholm.

Kaijser, A. 1999. The helping hand. In search of a Swedish institutional regime for infrastructural systems. In: Andersson-Skog, L. & Kranz, O. (red.), Institutions in the transport and communications industries (Canton, Ma), 223-44.

LaPorte, T. (ed.) 1991. Social responses to large technical systems. Control or anticipation. Dordrecht

Lilley, S. 1973. Technological Progress and the Industrial Revolution 1700-1914. In: Cippola, C. (Ed.), The Fontana Economic History of Europe Vol 3. London.

Mayntz, R. & Hughes, T. (eds.) 1988. The development of large technical systems. Frankfurt

Summerton, J. (ed.) 1994. Changing large technical systems. Boulder.

Summerton, J. 1992. District heating comes to town. The social shaping of an energy system. Linköping.

Tarr, J. & Dupuy, G. 1988. Technology and the Rise of the Networked City in Europe and America. Philadelphia.