2001-07-25

Redirecting infrasystems towards sustainability. What can we learn from history?

Arne Kaijser

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.[1]

On a macro level, infrasystems have brought about a transition from a basically "nature-based" economy, where the location of industries and other economic activities was primarily dependent on the access to waterways and natural resources, to a "culture-based" economy, where easy access to man-made infrasystems is decisive for the location of most economic activities. Infrasystems were first built between and within cities, and they have contributed to a fast urbanisation. The expansion of infrasystems has furthermore enabled an intensified exploitation of

[1] For a discussion of these concepts, see Kaijser 1984 and Kaijser 1999.

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. In short, the development of infrasystems is an important factor behind the sustained economic growth in the past two centuries. 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.[2]

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.[3]

Most of the articles in this volume deal with mental, legal and other immaterial frameworks forming barriers for people changing their habits and lifestyles in an environmentally sustainable direction. This article focuses instead on material

[2] This article deals with the Western World and focuses therefore on the *re*direction of infrasystems. However, I believe that the developing world could learn much from the historical experience in the Western World when building and expanding their infrasystems.
[3] Jonsson et al. 2000.

frameworks, which also have a strong influence on the behaviour of people, and which constitute important and long-lasting obstacles for changes towards sustainability. Furthermore, these material frameworks have a high degree of inertia over time. 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 article. 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 article is to contribute to such an understanding. The article covers a very broad topic and is therefore of a rather general nature.[4] 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. The structure of the article is as follows. First a short introduction to the research field is given and 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 section briefly outlines the impacts of infrasystems on society at large and especially on settlement patterns. The last section is devoted to a discussion of what lessons we can learn from history about the possibilities for redirecting infrasystems in the future.

Infrasystems as a field of research

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*,

[4] As the article 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.

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. Fundamental in his approach is to analyse how electricity systems in this broad meaning attain their specific form in the environment in which they develop. He tries to clarify the dynamics of these systems, and which kind of actors and problems that have been essential in different phases of their development. By comparing electricity systems in three countries he shows that they acquired varying *styles* in different countries and regions, due to the specific geographical, political, economical and cultural conditions of each region.[5]

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. Many of them have also made comparative studies of a certain system in several regions or countries.[6] The concept "large technical system" is very general, and my point with introducing the concept infrasystem is to focus on a certain kind of systems, namely those, which fulfil a basic function in society by facilitating movements of people, goods and information, and which are publicly accessible. I believe that a fruitful way to study infrasystems is by making comparisons among different kinds of systems. This has not been done very much within the LTS-tradition. Such comparisons can give us a better understanding both of the specific properties of individual systems and of the common characteristics of all infrasystems. And by combining comparisons between countries and between systems we can get insights into how infrasystems are shaped by nation-specific political and cultural traditions on the one hand, and by system-specific technical and economic properties on the other.[7]

Characteristics of infrasystems

[5] Hughes 1983.
[6] See for example the anthologies Mayntz & Hughes 1988; La Porte 1991 Braun & Joerges 1994 Summerton 1994; Blomkvist &Kaijser 1998; Coutard 1999; Andersson-Skog & Krantz, 1999.
[7] Kaijser 1999.

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.[8]

The character of the networks (in particular the links) 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. (These systems are sometimes referred to as grid-based systems.) 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.[9]

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. It goes without saying that it is utterly important to prevent major accidents leading to loss of lives and property, as such accidents can undermine the societal credibility of a system. But it is also essential to minimize small interruptions or delays. If these become frequent, users loose confidence and may change to other, competing systems. The American sociologist Charles Perrow makes a useful distinction between *tightly coupled* and *loosely coupled*

[8] Jonsson, 2000.
[9] Kaijser 1994.

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 is often a necessary to have one or several system operators 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. [10]

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. Often new office buildings surround the motorways leading to a major airport. A large part of these economic effects do not result in profits for the airport or airline companies, and are therefore called "external" effects. Such hoped for effects have often motivated public authorities to contribute to the investment in airports and similar facilities. 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

[10] Perrow 1984.

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. In 1802, Murdoch installed gas lighting in the premises of the Boulton & Watt Company in Birmingham, and it the following ten years gasworks were installed in about a dozen of other English factories.[11]

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 the German entrepreneur Friedrich Albert Winzer. His idea was to sell gas, not gasworks.

Winzer had built a small gasworks, imitating Lebon's plant, and had travelled across the continent trying to sell it, with little success. He came to London in 1803 and there he gradually came to the conviction that a precondition for gas lighting to reach a big market was that the investment cost for a gasworks could be distributed 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 (even though the cost to install pipes within a building still posed an obstacle) and also to supply gas for street lighting. For many years Winzer tried to convince capitalists, politicians and the public of the reliability and profitability of this plan. His ideas met fierce opposition not least from people with interests in the supply of existing means for lighting, whale oil and tallow. Finally 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.

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

[11] This example is based on Kaijser 1986 and Elton 1958.

the canals did) but to offer transport, both of passengers and of goods.[12] For achieving a fast expansion of the postal and telegraph systems it was essential that many kinds of interests (civil service, armed forces, railway companies, businessmen, newspapers etc.) could share the same service. 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.

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

[12] 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. See Lilley 1973 and Kaijser 1994.

authorities have primarily had a regulatory role, trying to avoid that system operators make an abuse of a monopoly situation.[13]

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.[14] 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. Similar increases of the load factor have taken place in many other systems as well, when new categories of customers or new types of services have been introduced. This has often been achieved through very deliberate policies from the

[13] See Kaijser 1999 and Dobbin 1994.
[14] Hirsh 1989.

system operators offering the new users favourable prices.[15] Thus, while economies of scale arose through an increase of the size of the technical components of a system, economies of scope were achieved through a better system architecture, a more efficient balance among the components within the system.

In infrasystems providing communicative services there is also another kind of economic force stimulating expansion that I would like to call *economies of reach*.[16] 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. This phenomenon was sometimes deliberately exploited. At the turn of the century there were two competing telephone companies in Stockholm, and they tried to increase the attractiveness of their networks by offering telephone subscriptions for free to doctors, pharmacists and other professionals that their subscribers wanted to reach.[17] Also when local telephone systems were interconnected by interurban lines, this implied a dramatic increase in the number of people that could be reached, which in turn spurred additional people to become subscribers. 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.[18] This paved the way for a fast increase in car ownership, which in turn gave an economic base (through taxes on cars and on fuel) for further investments in the expansion of roads.

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*.[19] Companies, which had invested much capital and other resources in a system (both equipment producers and owners and operators of systems), developed a

[15] Hughes 1983.
2 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.
[17] Heimbürger 1931, Helgesson 1999.
[18] Blomkvist 2001.

strong interest in the further expansion of the system. Furthermore, in many systems 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,* to use a concept introduced by Hughes. At many times a close co-operation among many influential actors towards a common goal shaped a strong force for expansion.[20]

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 using other means to fulfil the same function. Besides the costs for joining the new system, their resistance was often based in a lack of knowledge about how to use the new system or 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.[21]

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

[19] Hughes 1983 and Hughes 1987.
[20] See for example Fridlund 1999.
[21] Hagberg 1986.

new components, sub-systems or system-architectures were often the result, which in turn enabled a continued fast growth.[22]

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. These plants also contributed to severe environmental degradation, and still today, dangerous chemicals often heavily contaminate locations of previous gas plants. Another example is the introduction of water closets in the apartments of well-to-do urban households at the turn of the century. This improved the hygienic conditions for the users of the closets, but it also contributed to the pollution of rivers and lakes, which in turn affected many other people. Thus, while expanding infrasystems were often extremely effective in solving problems for some people, they usually also contributed to the creation of other problems affecting other, less influential 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. Likewise economies of scope are usually more or less exhausted once the load factor of a system reaches a certain level. Diminishing economies of scale and scope have sometimes been combined with a saturation of

[22] Hughes 1992. See also Fridlund 1999.

demand for the services of infrasystems. For example, in many industrialised countries a rather fundamental change of the "from bulk to bytes" occurred in the last quarter of the 20th century. A growing part of economic activity was directed from material intensive towards more knowledge intensive products and systems, and this was reflected in a much slower growth of the demand for services from for example energy, water- and transport systems. 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 *dis*economies 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. In fact, high-speed trains are taking over parts of the passenger traffic between major urban centres in Europe, partly due to the frequent delays of flights.

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.[23]

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.[24]

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

[23] Kaijser 1993.
[24] Grübler 1990.

more efficient than a separate production of each, and this was often a major incentive to build district-heating systems.[25] 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.[26]

Infrasystems and settlement patterns

In the previous section, I have discussed the internal dynamics of infrasystems. In this section I will focus on the external effects of infrasystems on settlement patterns. I will argue that in certain periods the development of one or several new infrasystems have provided radically new opportunities for commerce, industry and housing. I call these periods *logistical revolutions* to emphasise the broad scope of changes that are brought about.[27] These periods of time can be seen as formative phases, when different combinations of infrasystems are possible to achieve. The power elites of some cities or regions will grasp the new opportunities earlier than others, and by establishing a fruitful mix of systems they will get a competitive advantage over other areas. Later on, their choices often become a model for other cities and regions. I will briefly outline some examples in space and time of such logistical revolutions.

During the 16th and 17th centuries a logistical revolution took place in Europe. In the previous centuries maritime trade had largely been confined in two regional trading networks one around the Mediterranean Sea, and one in northern Europe around the Baltic and the North Sea. The development of better ships and the introduction of the compass and of accurate maps made it less dangerous for ships to travel past the Iberian Peninsula, and to cross the oceans to America, Africa and Asia. As a result, a truly global commercial system gradually evolved in the 16th century, with its first

[25] Summerton, 1992; Hård & Olsson 1995.
[26] Egyedi 1996
[27] See Andersson & Strömqvist 1988.

centre in Lisbon. The centre position was soon transferred to Antwerp, and a few decades later to Amsterdam. For more than hundred years Amsterdam was the uncontested commercial and cultural centre of the world.[28]

Why did Amsterdam become the leading commercial centre in the late 16th century? It was in part due to very favourable geographical conditions. More important, however, was the ability of the leading citizens of Amsterdam to grasp the potential of the new technological and commercial opportunities. In the second half of the 16th century, the leading merchant families of Amsterdam initiated heavy investment in harbour facilities, and the city harbour had soon room for thousands of sailing ships. Furthermore, they stimulated the development of a shipbuilding industry in Zaandam, just outside the city, powered by large windmills. It specialised in building the "fluitship", the best merchant ship of the time, and the Dutch merchant fleet became by far the biggest in the world. The ships did not merely bring goods to Amsterdam; they also brought merchants and sailors with information about distant market conditions. In 1600 or thereabouts, the city's rulers founded the Amsterdam Bourse and a special Exchange Bank, and these institutions became the heart of the commercial activities in the city. All these infrastructural and commercial investments provided the basis for Amsterdam to become the centre of a trading network stretching over all the Oceans of the globe.[29]

In addition to this long distance network, Amsterdam also became the centre of a local and regional transport system, which had no equivalent anywhere in the world. It was based on a very dense and fine-meshed network of canals and natural waterways, covering most of the Dutch Republic. These canals, which had been dug in the previous centuries for drainage purposes, encouraged a dynamic interaction between the growing towns and their agricultural hinterland. Furthermore, all these canals stimulated close interaction among the Dutch towns. In fact, over half of the population lived in urban areas. In the 17th century the Amsterdam rulers initiated a public transport system interconnecting all major Dutch towns. It was based on horse-pulled barges, or "trekschuiten". Travelling by trekschuit was comfortable and cheap. They went at about 7 kilometres per hour and were very punctual, keeping to

[28] Braudel 1992.
[29] Ibid; de Vries & van der Woude 1995,

timetables. About one million passengers a year travelled on these barges in the mid 17th century.[30]

Fig. 1. Map of the trekschuit-network in the mid 17th century. (To be added)

In short, the ruling merchants of Amsterdam became the avant-garde of a logistical revolution based on a perfection of water-based infrasystems across the oceans and within their region, which made their city the commercial as well as the cultural centre of the world.

From water-based to metal-based infrasystems

The Dutch had an exceptional transportation system *within* their country, due to special geographic conditions. But in most other countries inland transportation was slow and expensive, and formed a huge obstacle to economic development. In the mid 19th century, the building of railways and telegraph lines, opened up vast areas that had previously been virtually excluded from trade and commerce, and new towns and cities evolved along these networks of iron and copper. These new systems gave rise to a logistical revolution during which human built systems based on rails and lines of metal gradually replaced the previously dominant water-based infrasystems. Particularly in the United States with its vast distances and lack of roads, railways and telegraphs were of enormous importance, and Chicago became the railway city par excellence. Let me briefly explain why Chicago became so important.

The first efficient transportation route into the central parts of the United States was with steamboats along the Mississippi River and its tributaries in the 1820s. St. Louis, situated at the confluence of the Mississippi and the Missouri, became the most important trading town. When Chicago was established in 1830 it was also chosen from the water transport point of view. With the new Erie Canal it was possible for steamboats to go from New York to Chicago via the Great Lakes, and in

[30] de Vries 1981.

the rainy season it was possible to travel with a canoe from Chicago along a small river across the watershed down to the Mississippi. In 1848, the leading merchants of Chicago founded the Chicago Board of Trade, which became a very important organisation for the development of the city. When railways were being built in the mid 19th century westward from New York, Philadelphia, Boston and Baltimore, the Chicago Board of Trade was able to convince a number of railroad companies that Chicago would be the ideal end station to the west. At the same time, the Board of Trade organised the building of a whole number of small railway lines and canals to the west of Chicago which spread out, fanlike, over the prairie.[31]

Fig. 2. Map of railroads and canals to Chicago. (To be added)

The Chicago merchants started to organise a large-scale exploitation of the natural riches of the prairies to the west and of the forests to the north. Grain, animals and lumber were brought to the city in ever-larger quantities. The grain was graded into different qualities in gigantic steam-powered elevators before being transported by ship or train to the West Coast and further over the Oceans. The animals were slaughtered in the huge slaughterhouses equipped with ingenious dis-assembly lines, and the meat was then transported in refrigerated railroad cars to the cities in the East. The lumber was sorted and dried in vast lumberyards, and most of the lumber was then sold to the farmers on the prairies, who needed a lot of timber for their houses, barns and fences.

In 1848 the first telegraph line reached Chicago. The combination of the vast volumes of grain and meat passing through the city and the access via telegraph to information about market conditions all over the world meant that the great hall of the Board of Trade became the world's leading food market in the 1860s. Thus, like their colleagues in Amsterdam before them, the leading merchants of Chicago became the avant-garde of a logistical revolution, in this case based on the railway and the telegraph. They grasped the potential of these infrasystems, and succeeded in using them to gain control over the exploitation of the enormous natural riches of the

[31] Cronon 1992.

prairies and the forests. They turned Chicago into Nature's Metropolis; to use a term coined by the historian William Cronon.

Pedestrian cities

So far I have mainly discussed the role of what can be called *external* infrasystems in relation to cities, that is transportation and communication networks connecting cities with their hinterland and with distant markets. What about the role of the *internal* infrasystems within city borders? Up to the mid-19th century, the developments of external infrasystems were most vital to the development of settlement patterns, but in the past hundred and fifty years the ability to develop internal infrasystems has been increasingly important to the development of such patterns.

In the 19th century a very fast urbanisation took place in the Western world. It was spurred by the building of railways and telegraph lines, which provided a radical improvement in transport and communications, but only for cities and towns, not for the countryside. There were also other new infrasystems such as gasworks for lighting, which were available only in cities. Previously the availability of different natural resources had often been decisive in the location of industrial activities, but increasingly the availability of man-made infrasystems became decisive. Most of these systems were only accessible in cities.[32]

The cities of the 19th century were pedestrian cities. There were no efficient systems for transporting people within the cities, and thus most people had to walk to their work. This meant that factories and dwellings could not be too far apart, and larger cities in particular became very densely built and overcrowded. This implied a number of big threats. Sanitary and environmental conditions became more and more miserable and mortality rates increased. Big fires and popular riots were other dangerous threats. Finally the streets became more and more congested, making the transportation of goods and people more difficult and time-consuming, and this was a threat to the commercial activities in the cities.

A number of new infrasystems were developed to cope with these problems. Many of these systems implied a specialisation and separation of different kinds of transport. In the first phase, a number of new pipe networks were built underground, below the city streets including gas, water and sewage systems. The latter two were especially important. They, in fact, addressed all the pressing problems mentioned above. When most inhabitants in a city had access to clean water and effective sewage, the mortality sank dramatically. Furthermore, fire hydrants improved fire fighting and could also be used to suppress riots. And finally, the water and sewage pipes saved the streets and staircases from a lot of bulky transportation.[33]

The congestion of the streets was, however, not solved by these new underground networks and in big cities like London and Paris the situation became particularly chaotic in the middle of the 19th century. Different strategies were developed in the two cities for solving the problem. In the London region, political power was distributed over more than 300 different bodies, which made concerted action to cope with the problems very difficult. The building of an underground railway, the Metropolitan Line, linking all the main-line railway termini in the city, was by some groups seen as a radical way of improving passenger traffic. However, the construction of this line was very complicated and met much opposition, and it took twenty years to complete it. Furthermore, the smoke from the steam engines made journeys on this underground railway very unpleasant. It was not until the turn of the century after the introduction of electric traction, that the underground became a really viable alternative. In Paris, a more radical approach was pursued in the 1850s by the new, energetic prefect of the city, Georges Eugène Haussmann. He was appointed to his post by Napoleon III, and had a strong backing from the emperor, which gave him a very powerful position. Haussmann carried through a drastic reconfiguration of the entire city. Lots of old houses were torn down to give way to new broad boulevards, which provided fresh air and plenty of space for pedestrians and coaches. In addition, the boulevards made it much more difficult to organise riots and revolts such as the city had experienced in 1830 and 1848.[34]

[32] Many examples are analyzed in Tarr & Dupuy 1988.
[33] Jonsson et al. 2000.
[34] Hall 1998.

We can talk of an intra-urban logistical revolution taking place in most major cities in the western world in the second half of the 19th century, and appearing in different forms, as I have indicated with the examples of London and Paris. But in almost all cases it involved the introduction of a whole array of new infrasystems providing efficient means for transportation of people, goods and information within the city borders. These systems made use not only of the space underneath the streets (gas, water and sewage, and subways), but also above the roofs (telephony and electricity), making possible an increase of the population and an intensified use of the urban space. It was the logistical revolution of the dense city.

Urban sprawl

Around the turn of the century new infrasystems helped to break the old boundaries of cities, and a new form of urban expansion began. Electric trams and trains made it possible to commute from suburbs to the city-centre, and the access to telephone and electricity in the suburbs facilitated this exodus. The well-to-do families were the first to move to the new green and healthy suburbs, and the middle strata soon followed them. The poorest often remained in downtown housing areas, which turned into slums.[35]

The first wave out of the cities was organised first around tram and railway lines and somewhat later also along bus routes. There was a certain concentration also in the suburban areas, because people had to walk or bike to the nearest tram- or bus-station. Thus, distinct settlement patterns evolved characterised by nodes along the new transportation lines. Not only dwellings were built in the suburbs; more and more factories, offices and shops were also located there, reachable by public transportation. But the different categories of activities were located in separate places, according to a new emerging planning ideal of functional separation.

The exodus out of the dense cities can be called the logistical revolution of urban sprawl. There have been two phases of this revolution in the past century. The first wave was centred on public transportation systems, and led to distinct suburban concentrations around the cities. The second phase centred around the motor car, which made it possible to live further away not only from the city but also from suburban centres, and this contributed to urban sprawl over vast areas. More roads had to be built to cope with growing traffic volumes, and new shopping centres and work places emerged along these roads accessible only to households with cars. These developments stimulated more and more people to go by car, and in many urban regions this has led to a vicious circle of increasing traffic congestion.

However, there are big differences among cities regarding their degree of sprawl and their dependence on the car. One important factor seems to be the age of the city. In general, young cities (which are more common in North America and Australia than in Europe) have a high degree of sprawl because they have experienced most of their growth after the introduction of the car. Los Angeles is the archetype of this development. Already in the mid 1920s almost every household had a car, and at this time the city politicians and planners decided to develop a new network of freeways instead of trying to preserve the existing streetcar and light rail systems. This strategy led to a decline of the old downtown area and a very high degree of sprawl and an almost total dependence on motorcars.[36]

In contrast to cities like Los Angeles, most European cities already had a rather large and densely built downtown area when the car was introduced, which made a whole-hearted car strategy almost impossible due to lack of space for roads. Many European cities have instead developed a conscious strategy of supporting and developing public transport. A good example is Stockholm, which is a city largely located on islands, and thus dependent on a limited number of bridges. This made transportation a critical issue in the mid 20th century as more and more households wanted to move out of the inner city. In the decades after World War II, Stockholm built an elaborate underground system under the downtown area which later spread far out of the city. The construction of the underground lines was closely connected to the building of a whole series of new suburbs along these lines, like beads on a necklace. These suburbs were carefully planned with a commercial centre, schools and high-rise buildings close to the station, and with lower dwellings further away

[35] Ibid.
[36] Ibid.

from the station, but still within walking distance. Furthermore there were plenty of forests and recreation areas close to each suburb. This co-ordinated suburban development along underground lines was made possible through a rather high degree of mutual understanding among the leading politicians from different political parties and also among politicians and real estate owners. As a result of this strategy, Stockholm achieved a very high percentage of public transport use compared to many other cities of a similar size.[37]

Fig. 3. Map of underground lines and new suburbs built in Stockholm after W.W.II. (To be added)

With this short historical exposé over logistical revolutions in the past, I have primarily wanted to illustrate that the combined effect of intertwined infrasystems on the spatial distribution of commerce, industry and settlements can be very powerful. I want to emphasise that there has not been one uni-directional development. There are often many different ways in which infrasystems can be combined. A logistical revolution should thus be seen as a formative phase, when new infrasystems offer new opportunities and when new combinations of infrasystems are possible to achieve. Cities have differed in their response to these opportunities. Above, I have primarily discussed cities, in which the power elite has been particularly skilful in grasping the opportunities offered by new infrasystems and has developed clear strategies and plans for how to implement them at an early stage. Many other cities and urban regions have had a more piecemeal approach, and have rather followed the examples of others.

Once an urban region has chosen to develop and combine new infrasystems in a certain way, a process of embedding starts making future change difficult. A distinction can be made between *structuring* and *adaptive* infrasystems. The dominant transportation system at a given time often has a stronger structuring effect than other systems, which rather adapt to the new patterns shaped by the transport systems. Therefore the choices and the designs of transportation systems have often been particularly important for the long-term development of urban regions. Another

[37] Johansson 1987; Hall 1998.

way to phrase this is to say that rails and roads have a strong tendency to almost literally contribute to the phenomenon of path-dependency.[38]

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. "[39]

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 article, 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. I want to underline that I am deliberately vague when talking about a redirection of infrasystems "in a sustainable direction", and what this should imply more specifically. In my opinion it is not the task of a historian to define what kind of changes that are desirable for the future. But a

[38] David 1988.
[39] Hughes 1983, p. 465.

historian can try to assist those that want to bring about change, by trying to provide lessons about the general character of processes of change. That is the aim of this section.

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”.[40] 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. These reforms are in an early stage and have not become firmly embedded as yet. 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.

[40] Re-regulation is in fact a more adequate term. That is; regulation has changed, not diminished.

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. Leading engineers and scientists have often been engaged in such efforts, and at a number of times, radical new components or entirely new system designs have been the outcome of such efforts. 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.

The concept “functional equivalent” is important in this context. For example, in the case of CFC-gases, alternative technical solutions – functional equivalents to the CFC-gases - existed, which made it possible for legislators to pursue tough policies, demanding an abandonment of CFC-gases. It is often of critical importance to be able to show that a functional equivalent to a polluting component or system exists, even if it is expensive to make a substitution. Research to develop such functional equivalents may pose a threat to the dominant actors within an infrasystem, and therefore public funding of such research is essential.[41]

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

[41] Kaijser et al. 1988.

communication technologies 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. A breakdown in one system may get almost instant repercussions in many other systems. This vulnerability was clearly illustrated by the extremely costly preparations for avoiding breakdowns on the New Years night of the new Millennium.

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.[42] 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. Using existing networks, does not provide the same capacity as optic fibres, but is much cheaper and can be implemented much quicker. In the case of Internet, the owners of the “host networks” are happy to provide capacity to Internet traffic as this does not threaten their traditional services and increases their incomes.

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

[42] 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.

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.[43] 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.

Infrasystems and settlement patterns

A fourth lesson is that there is a strong interrelation between infrasystems and settlement patterns, in particular in urban regions. Most infrasystems have first been built between or within urban areas, and the access to these systems became an important competitive advantage for cities and towns in relation to rural areas and spurred a fast urbanisation. Furthermore, the development of new systems, and in particular transportation systems, influenced the status among cities. Those that were able to attract or build such systems at an early stage often prospered and advanced in the urban hierarchy, while those that were late often sank. Until the late 19th century, all cities were basically pedestrian cities, as there were no efficient systems for transporting people within them. Around the turn of the century, the introduction of electric trams, commuter trains and later on also buses and cars enabled those who could afford it to move out to new suburbs. The ways, in which these transportation systems were built, had a strong and long-lasting impact on urban settlement patterns. These systems thus had a structure-shaping character.

A conclusion of this is that it is absolutely essential to make assessments of the long-term structural effect when the construction of new airports, streetcars, highways,

[43] Ekman 2000.

bridges or other large infrasystem projects are being considered and to let such assessments have a key role for the decision. This is, unfortunately, seldom the case. Mostly, investment decisions are largely based on assessments of the effects on traffic flows once the project is completed. The mega-cities in the third world are the most rapidly growing cities in the world, and it is particularly important to develop and implement policies for infrasystem development in these places, which focus on long-term consequences for settlement patterns.

Historically, transportation systems have had the strongest structure-shaping effects. However, in the future information technologies may partly take over this role. In the industrialised world a large building stock has already been built, and a redistribution of activities within the existing housing stock may become more important then the construction of new buildings for lifestyles and travel patterns of urban populations. New information and communication technologies are an important factor in this context, as they provide new opportunities for where to carry out many kinds of activities. We seem to be in a formative phase, as these technologies can be used for many purposes and in different ways. One scenario is the revival of more integrated towns, with shorter daily travel needs as a result. Another scenario is a further urban sprawl. A crucial question for a societal development in a sustainable direction is what kind of policies that will prevent the latter scenario.

***

I hope that this article 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.

References:

Andersson-Skog, Lena & Olle Krantz 1999, *Institutions in the transport and communication industries. State and private actors in the making of institutional patterns, 1850-1990* (Canton, Ma.)

Andersson, Åke E. & Ulf Strömquist 1988, *K-Samhällets framtid*.(Stockholm)

Blomkvist, Pär & Arne Kaijser (eds.) 1998, *Den konstruerade världen. Tekniska system i historiskt perspektiv* (Stockholm)

Braudel, Fernand 1979 (Engl. transl 1992), *Civilization and Capitalism 15th to 18th Century, Volume III, The Perspective of the World* (Berkeley)

Braun, Ingo & Bernward Joerges (eds.) 1994, *Technik ohne Grenzen* (Frankfurt am Main)

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

Cronon, William 1992, *Nature's Metropolis: Chicago and the Great West*

David, Paul 1988. *Path-Dependence: Putting the Past into the Future* (Stanford)

Dobbins, Frank. 1994, *Forging Industrial Policy. The United States, Britain and France in the Railway Age* (Cambridge, MA)

Egeydi, Tineke 1996, *Standardisation of the container. The development of a gateway technology in the system of cargo transportation* (Stockholm)

Ekman, Tomas 2000, *Kampen om gatan: Avvecklingen av spårvägstrafiken i Stockholms innerstad, 1920-1967* (Stockholm)

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

Fridlund, Mats 1999, *Den gemensamma utvecklingen: Staten, storföretaget och samarbetet kring den svenska elkrafttekniken* (Stockholm)

Grübler, Arnulf 1990. *The Rise and Fall of Infrastructures. Dynamics of Evolution and Technological Change in Transport*.(Heidelberg)

Hall, Peter 1998, *Cities in Civilization* (New York)

Hagberg, Jan-Erik 1986. *Tekniken i kvinnornas händer. Hushållsarbete och hushållsteknik under tjugo- och trettiotalen* (Malmö)

Heimburger, Hans 1931. *Svenska telegrafverket: historisk framställning, Band I: Det statliga telefonväsendet, 1881-1902* (Göteborg)

Helgesson, Claes-Fredrik 1999, *Making a natural monopoly* (Stockholm)

Hirsh, Richard 1989. *Technology and Transformation in the American Electric Utility Industry* (Cambridge)

Hughes, Thomas P. 1983, *Networks of power. Electrification in Western Society 1880-1930* (Baltimore)

Hughes, Thomas P. 'The evolution of large technical systems', in Wiebe Bijker, Thomas Hughes & Trevor Pinch (eds.), *The social construction of technological systems. New directions in the sociology and history of technology* (Cambridge, Ma), 51-56

Hughes, Thomas P 1992. 'The Dynamics of Technological Change: Salients, Critical Problems, and Industrial Revolutions' In: Giovanni Dosi, Renato Gianetti & Pier Angelo Toninelli. (Eds.) *Technology and Enterprise in a Historical Perspective* (Oxford)

Hård, Mikael & Sven-Olof Olsson 1995 ' Enforced Marriage: How District Heating and Electricity Systems Have Been Combined' in Arne Kaijser and Marika Hedin (eds.) *Nordic Energy Systems: Historical Perspectives and Current Issues* (Canton,) Johansson, Ingemar 1987, *Storstockholms bebyggelsehistoria. Markpolitik, planering och byggande under sju sekler* (Stockholm)

Jonsson, Daniel & Anders Gullberg, Marie Jungmar, Arne Kaijser, Peter Steen 2000 *Infrasystemens dynamik - om sociotekniska förändringsprocesser och hållbarhet* (Stockholm)

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

Kaijser, Arne 1986, *Stadens ljus: Etableringen av de första svenska gasverken* (Malmö)

Kaijser,Arne & Arne Mogren, Peter Steen 1988, *Att ändra riktning: Villkor för ny energiteknik* (Stockholm)

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

Kaijser, Arne 1994, *I fädrens spår. Den svenska infrastrukturens historiska utveckling och framtidda utmaningar* (Stockholm)

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

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

Lilley, Samuel 1973. 'Technological Progress and the Industrial Revolution 1700-1914'. In Carlo Cippola (Ed.), *The Fontana Economic History of Europe Vol 3* (London)

Mayntz, Renate & Thomas Hughes (eds.) 1988, *The development of large technical systems* (Frankfurt)

Summerton, Jane 1992, *District heating comes to town. The social shaping of an energy system* (Linköping)

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

Tarr, Joel & Gabriel Dupuy 1988, *Technology and the Rise of the Networked City in Europe and America* (Philadelphia)

Vries, Jan de 1981, *Barges and capitalism. Passenger transportation in the Dutch Economy, 1632-1839* (Utrecht)

Vries, Jan de & Ad van der Woude 1995, *Nederland 1500-1815. De eerste ronde van de moderne economische groei* (Amsterdam)