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Infrastructures and Societal Change. A View from the Large Technical Systems Field

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ABSTRACT *Infrastructural and societal changes intertwine in multiple ways. This makes the societal implications of infrastructural projects difficult to assess and anticipate. Yet in present day network societies this task is particularly urgent. This paper first identifies two positions that tend to monopolize and deadlock debates. Next it examines two decades of research in the Large Technical System (LTS) research field for alternative approaches to this issue, before finally suggesting distinguishing between the four increasingly indirect moments of (co-) construction of infrastructures and societies. These may be related causally, but also add their own moments of contingency, agency, and choice.*

Understanding the societal implications of infrastructural technologies is of vital importance to the analysis of present day network societies. However, as infrastructural and societal changes intertwine on many levels over large time spans, these implications are wide reaching and diverse. They pose a particular challenge to technology assessment studies that try to assess and anticipate the potential implications of infrastructural projects.

There are not many studies that address the complex causal relationships between infrastructural changes and exactly the variety of implications that makes the topic so important. Two powerful narratives tend to structure public debates. Each privileges one particular aspect of simultaneous infrastructure and society building. The first, sometimes called the 'ideology of circulation', connects infrastructural integration of peoples with economic and ideological exchanges in the service of joint progress, democracy and peace. The second, pitched against the former, tends to critically reduce the implications of infrastructural changes to the economic or political agendas of powerful elites designing infrastructures for their own benefit. Both narratives are reductionistic and at cross-purposes, and have deadlocked discussions from at least the mid 19th century.

The diversity of possible implications of infrastructural changes is better appreciated by those who regard infrastructures as a 'material base' of society,

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enabling a myriad of social changes, for good or for worse.[1] In this tradition, however, causal relations tend to remain unspecified and implicit. This is true even for Castells' extensive study of the network society in the Information Age. The reader is given a summary of recent Information and Computer Technology (ICT) developments and a disclaimer denouncing technological determinism, but the postulated relationships between ICT developments and an impressive range of social events remain theoretical and implicit.[2]

This paper aims to develop a framework of analysis geared to address a greater variety of societal implications of infrastructural changes with due regard for the nature of the causal relations that connect the two categories of events. 'Infrastructural change' is used as shorthand for the development of infrastructural or 'network' technologies; the term 'societal implications' here embraces infrastructure-related changes in social, technical and natural environments of modern men and women.

By way of introduction, the first section summarizes the two above-mentioned narratives on infrastructures and societal change that assessments of infrastructure-related societal changes should be able to recognize and transcend.

The following section reviews a body of literature that seems better suited to address the variety of infrastructure-related societal changes. The so-called Large Technical Systems (LTS) research field has claimed the interaction between infrastructural and social changes as its domain since the mid 1980s. I shall not discuss here the field's most highly profiled research themes—i.e. the history, dynamics and governance of these systems; these have been reviewed elsewhere. Instead I shall review canonical as well as (because of language barriers) less accessible contributions to this literature that are relevant to the more 'hidden' research question of the societal 'implications' or 'consequences' of infrastructural changes.

Using this literature review, the third section suggests a framework that brings out four distinct, increasingly indirect moments of co-construction of societal and infrastructural changes, which can be related causally, but may also add their own moments of contingency, agency or choice (and thus suggest potential policy opportunities). The paper repeatedly refers to the debate on technological determinism, which continues to influence much of the research in this realm.[3]

The Ideology of Circulation and its Critique

When discussing the societal implications of infrastructural change, it is important to recognize at least two powerful narratives that manifest themselves as deep grooves shaping public and academic debates. The first of these narratives, sometimes identified as a 'modern ideology of circulation', emerged with early Capitalism and the Enlightenment and is believed to have provided the 'cultural origins' of the modern human preoccupation with network building. Its history has been amply investigated. I will briefly summarize the main junctions in this impressive line of thought.[4]

The modern ideology of circulation had matured by the mid 19th century, but its roots are still older. While 17th century merchants invented the 'triangle trade' and French administrators initiated a reorganization of national space through road and waterway construction, explicit ideas of circulation penetrated the emerging thought on political economy. As the title suggests, William Petty's *Political Anatomy of Ireland* (1672) illustrates how Harvey's publication on blood circulation in the body (1628) became a powerful metaphor for society as composed of guiding brains and vital organs connected by circulation. For Petty, tradesmen played the 'role of veins and arteries, to distribute in a circulatory movement the blood of the nourishing sap of the Body-Politick'.[5] The body metaphor for society has reappeared in many forms since that time.

Eighteenth century thinkers further developed this understanding of society in terms of circulation. The work of Turgot is particularly important. With the Physiocrat school he shared the idea that value stemming from agriculture had to be cycled through society as effectively as possible, for which purpose the State ought to construct dense road and canal networks. But in his famous work *Discours sur les progrès successifs de l'esprit humain* (1750) he also addressed the circulation of rational knowledge. If the gradual enlightenment of the human mind was proportional to their contacts with other groups, communication lines crossing local or national borders were crucial means to encompass an increasing part of the globe.

Several of these ideas would pass into liberalism with Adam Smith (1779), who found transborder routes of transport (especially navigation) and a credit system pivotal to increase markets, enhance specialization and the transnational division of labour, and ultimately produce moral refinement and abolish hostilities in the 'universal mercantile republic'.[6] However, the ideology of circulation is generally held to have culminated with the Saint-Simonians in the first half of the 19th century. Replacing division of labour with co-operation towards a common goal, Claude Henri de Saint Simon emphasized the role of 'networks' in the shaping of a 'universal association'. In his proposals for a European Society (1814) roads, canals, drainage infrastructures, and money reforms were crucial. His follower and French minister Michel Chevalier spoke of a 'circulating civilisation', in which 'spiritual' (credit) and 'material' networks provided cohesion to the social organism: 'railways have more relation to the religious spirit than we think. Never has there existed an instrument of such power to link together scattered peoples'.[7] Saint-Simoneans were involved in preparations of the Suez Canal, and set up railway and shipping companies, global industries and credit multinationals.

The ideology of circulation regularly re-emerged in 20th century thought. While infrastructure building became a focal point of the shaping of a unified and peaceful Europe, MacLuhan and Fiore's (1968) vision of a 'global village' suggested that television would abolish war and produce a global community. More recently, a similar rhetoric accompanied electronic superhighway building: For global information infrastructure proponent US Vice-President Albert Gore (1994), the 'network of networks' would re-unite the 'great human family', 'promote the functioning of democracy by greatly enhancing the participation of citizens in decision making', and 'greatly promote the ability of nations to cooperate . . . I see a new Athenian age of Democracy . . . let us work to link the people of the world'.[8]

The 'ideology of circulation' has provoked its share of criticism. To scrutinize this ideology is also the purpose of some of its historiographers, on whom this brief survey is based. The Belgian sociologist Mattelart reconstructed the history of circulation (or 'communication') in Western thought with the purpose of exposing the difference between 'utopian discourse on promises for a better world due to technology' and 'the *reality* of struggles for control of communication devices and control over norms and systems' [my emphasis].[9] This critique of ideology approach illustrates a second and equally influential narrative on infrastructures and social change, which tends to reduce infrastructure building to an important arena in which powerful groups compete for economic or military supremacy. Its compatibility with current anti-globalization sentiments is obvious. One finds a similar analytical strategy, though more ambiguous in its normative overtones, in the American geographer Hugill's praiseworthy attempt to insert the 'material base' into world systems theory. Re-narrating five centuries of capitalist expansion, Hugill demonstrates how competing polities consciously engaged in infrastructure building to achieve economic or military hegemony.[10]

This second narrative, too, has a long history. Mattelart finds an early critical ally in Proudhon (1855), who emphasized that social reform depended on the ownership and use of networks rather than their construction: 'the length of railway lines in operation in France has tripled. Since then we have not seen the slightest idea circulate'. Proudhon saw promises of infrastructural change as diversions from 'real problems' such as urban crime and misery; he even accused the French government of 'tending to turn a great nation, free until now, into a population of servants and serfs' through a 'monarchic and centralizing' railway network.[11] Also other critics turned away from Saint Simonian expectations of networks and placed their hopes in social reforms instead.

The competitive potential of infrastructures is amply recognized in the history of strategic thought. Napoleon's recognition of the importance of military supply lines was further developed by Prussian officers as Von Moltke and Pönitz, who by the mid 19th century viewed railways as 'military operation lines' crucial to war and national defence. The importance of railroads in economic competition was formulated by the German economist Friedrich List, who proposed to counter British economic dominance in the early decades of the 19th century with internal German integration as well as colonial lines. Military and economic concerns converged around the turn of the 20th century in the work of Admiral Mahan of the Naval War College, theorist of an increasingly expansionist USA, who saw control of sea routes as means to 'modify the political and industrial relations of mankind' and proceeded to design a map of strategic positions to be occupied by the USA. Similar ideas played out in Ratzel's (1897) founding work on political geography, or geopolitics. For Ratzel, circulation ('Verkehr') of people, goods and information was the backbone of the control of space, and 'space is power'.[12]

These two 'grand narratives' on infrastructures and societal change are both reductionistic and at cross-purposes. As potentially contradictory views they are rarely combined. Moreover, both focus on effects produced during the construction phase and make the decision phase the sole arena for influence and conflict. When applied to for instance the topic of globalization, the debate is quickly deadlocked. The possibility that consequences can be produced much later, for instance by users, is neglected. Assessments of infrastructure-related societal changes should therefore recognize and transcend these positions.

Large Technical Systems and their Implications

How, then, does the LTS research field, that claims the interaction of infrastructural and societal development as its domain, address the societal implications of infrastructural changes? This field needs only little introduction. LTS authors agree to situate the origins of their field in Thomas P. Hughes' book on the development of electricity supply networks (1983), which is cited for at least two important reasons.

First, it revived the sense of enormous societal importance of infrastructures originally touched upon by the *Annales* school in socio-economic history. With Valéry, Bloch and Braudel, Hughes sees electricity supply systems and other 'large technical systems' as new, human-made 'deep structures' in society. Strongly influencing where and how people live, work, play, and make war, they may have surpassed politics and natural geography in prominence.[13] Similarly the array of LTS anthologies, which serve as the main forum for English-language discussion of the field, greatly emphasize the societal importance of LTS in their prefaces and introductions. Invariably, the argument is that LTS are a historically and sociologically very important category of phenomena begging for their own field of research.[14]

Second, Hughes advocated a 'sociotechnical systems research methodology', sometimes referred to as 'the' LTS approach (although it actually comes in many variations) to investigate this category of phenomena. The construction of LTS is analyzed from the perspective of privileged actors ('system builders') who manipulate and juxtapose 'heterogeneous' elements, ranging from artefacts to organization structures, licensing strategies, and advertising, into the coherent sociotechnical wholes that currently structure modern societies. Obviously, the argument borrows its synthetic and multidisciplinary features from general systems theory.[15] However, deviating from general systems theory, Hughes prefers few concepts liberating historical imagination to formalization (which he rejects as 'physics envy'[16]). Also, he introduced a 'follow the actor' strategy in the study of dynamic society-wide structures and thus accounts for system changes by dissolving the actor–structure cleavage. These features may explain the diffusion of this approach in historical, sociological and policy-oriented technology studies.[17]

Before examining how authors address the societal implications of LTS, two observations are apposite. First, the above suggests that the notion of 'large technical systems' has a double meaning: it refers to a category of phenomena as well as a research methodology. Indeed, some authors do not distinguish between research object and method. But surveying the field—and certainly for the analytical purposes of this paper—it is wise to keep these meanings separated. In the late 1980s 'the' LTS approach was proclaimed as one of the 'new directions' in technology studies and should as such be applicable not only to the phenomena of LTS, but to any kind of technology.[18] Conversely, other approaches have been used to study LTS, although they have not been equally highly profiled in the field's canon.

Second, there is no consensus on a strict definition of the research object LTS.[19] Clearly LTS resemble society-wide structures usually called 'infrastructures' (factories or hospitals are considered 'nodes' or 'junctions' rather than LTS). Yet some authors define such structures as sociotechnical entities and reject any distinction between 'the technical' and 'the social', while for others LTS rather are society-wide 'technologies'. Some presuppose central system builder control over all system elements (and exclude more anarchistic systems such as road and water transport), while others make a point of studying self-regulation or 'loosely-coupled systems'. Some define LTS by function (communication, transport, energy supply) while others investigate their multifunctionality. In this paper I do not aim to define LTS, but focus on societal implications of infrastructural technologies and review those LTS studies that are relevant to this issue.[20]

The LTS field boomed in the 1980s and 1990s, and a review must necessarily be selective. For the purposes of this paper, I have focused on interpretative, synthetic studies of LTS development at the expense of a multitude of studies addressing individual systems in individual regions or countries. There is no shortage of such broader LTS studies either; this essay uses publications in English, Swedish, German and French. In this literature, I think one can distinguish at least five analytical strategies to address the societal implications of infrastructural changes.

Building Sociotechnical Systems

A first analytical strategy to investigate the societal implications of infrastructural technologies can be found at the heart of the LTS canon.[21] This strategy applies 'the' LTS approach to its topic. Studying the construction process of infrastructures *qua* sociotechnical systems unravels not only the complex shaping and functioning of infrastructural technologies, it also spotlights non-technical constructions of system builders, which, although intrinsically tied to the sociotechnical system, constitute important societal events in their own right.

Hughes' well-known account of Thomas Edison's construction of a sociotechnical electricity supply system illustrates this point. The system included novel technologies such as the parallel distribution network, a high resistance light bulb (to decrease the electricity flows and thus copper costs in parallel networks) and the low internal resistance generators (matching the low external resistance in parallel networks). These technologies were inspired by a new concept of electricity supply, of sales to an external public (modelled after public gas supply), which is still with us today. The working of the system was much indebted to Edison's business structure, including a holding company, separate production companies for light bulbs, tubes and machinery, and of course an array of local electric utilities. Together with its main competitor, the Westinghouse Company, the Edison companies (later General Electric) would shuffle the US business landscape. The electric industry became a first rank economic, political and employment factor in the USA, as railroad companies did in the

19th century and ICT companies do today. Similarly, Edison and other system builders moulded relationships between utilities and local and state governments as franchises were important components of this new system, and played a role in the history of advertising.[22] Hughes' point was that these heterogeneous efforts jointly shaped a successful and stable sociotechnical system. In terms of the research question of the present article, however, this approach suggests a strategy to access those societal changes related to infrastructural change that were already shaped during the sociotechnical construction process.

'The' LTS approach not only addresses non-technical constructions of system builders; it also uncovers how the agendas of system builders become inscribed in the technical features of infrastructural technologies—the point the second narrative summarized above. To take one more example from the realm of electricity supply, the expansion from state power grids to interstate power grids in Australia had only insignificant economic advantages of scale, load factor or economic mix. Instead, the shaping of an interconnected system allowed utilities to break the power of unions, which were organized at the state level.[23]

Bijker, in his survey of sociotechnical technology studies, thus rightly counts 'the' LTS approach as an approach combining the 'social shaping of technology' and the 'technological shaping of society'.[24] It should be noted however that this canonical interpretation of 'the' LTS approach does not explicitly ask the question concerning 'societal implications of LTS'. If infrastructures and their societal implications are constructed simultaneously, in one and the same process, this phrasing seems meaningless. This non-asking, however, has its backdrop. Addressing only those 'implications' that are part and parcel of the sociotechnical construction process, the publications that proclaim the wide-reaching societal effects tell us very little about the acclaimed changes in how people live, work, play, or wage war. Such events seem to remain out of their analytical reach. It is worthwhile, therefore, to look beyond the canon of the field.

Reasoning from LTS to Societal Effects

The LTS literature researched for this paper includes a handful of publications that do explicitly explore the societal implications or 'consequences' of LTS. They seem to understand that dangers to academic scrutiny do not stem from wrong answers to posed problems, but from the failure to ask certain questions.[25] Unfortunately these studies hardly refer to each other, probably because they are published in different languages. Therefore I shall attempt to draw them into the debate by categorizing them as additional methodological strategies to address the societal implications of infrastructural changes.

A first additional strategy is to depart from the intrinsic properties of LTS, and subsequently relate these to various external societal 'effects'. Two authors, who in my view use this strategy to investigate the effects of LTS in the most general way, are the Swedish historian Arne Kaijser and the German sociologist Renate Mayntz. Both produce a list of four kinds of effects.

Kaijser groups effects in four different societal domains: he speaks of the 'meaning', 'effects', or 'impacts' of LTS on (1) economic growth, (2) geography, (3) the political/military sphere and (4) environment and health. This includes, for instance: how transport innovations enabled the creation of European—and later worldwide—trade systems; how waterways and roads determined where towns were founded, and (later) how access to railway networks, water supply systems, sewage systems, and electricity systems made some towns grow at the expense of others; and how electricity supply systems much improved the urban environment, but unexpectedly helped create new forms of regional and global pollution such as acid rain and the greenhouse effect.[26]

In contrast to this empirical grouping of effects, Mayntz identifies four 'theoretical' societal implications of LTS. Two of these, she claims, are fairly well known. First, the development of LTS led to the constant increase of achievements of mankind and, second, this also led to a complementary but equally steady increase in risks. This development partly followed the increased accident potential of ever more complex technologies and partly the growing dependence of societies on the functioning of infrastructural systems. In addition, two other effects seem less well recognized. LTS increasingly structured different 'social function systems', such as politics, education, religion, industry and science. These social function systems became increasingly dependent on LTS and thereby less flexible—LTS shape their course of development much more than any earlier form of 'technification'. Finally, centrally coordinated LTS were a driving force in the tendency towards organizational hierarchization and centralization, for instance in state bureaucracies and industry. Notably, this synchronous development in LTS, state and industry provoked massive opposition in the 1970s and 1980s and current developments are again characterized by a similarly synchronous development in LTS, state and industry towards horizontal organization structures and decentralization.[27]

Other authors following this line of reasoning have added different types of effects. Worth mentioning is Sachs' observation that LTS create new achievements and thereby also possibly a new consciousness or 'mental spaces' (feelings, knowledge, hope), including new sciences.[28] This is reminiscent of Schivelbusch' classic study *Geschichte der Eisenbahnreise*, which investigated how intrinsic properties of railway transport affected the human perception of space and time. The stagecoach provided a continuous experience of space, mimetically connected to the landscape. The uniform, inanimate and fast movement of the train, however, detached the travellers from the local landscapes. It gave the first travellers an experience of alienation from local landscapes and disorientation because of the new bombardment of visual impressions: they spoke of the annihilation of space and time. This disorientation was soon relieved, however, by a new form of perception (the 'panoramic' vision), in which the landscape was seen as in a theatre, and speed was praised for making visible vast changes in the landscape and thereby bringing it truly alive.[29]

Neither this analytical strategy, nor its results have been uncontested. The strategy itself is prone to accusations of technological determinism (I will briefly return to this below), while theses on the economic importance of railroads and the immanent demand for centralized control of LTS, for example, remain subject to controversy.[30] Here it suffices to say that by reasoning from intrinsic properties to societal phenomena, this approach can highlight important infrastructure-related societal changes that remain invisible in studies that investigate the perceptions and actions of system builders.

Reasoning 'Backwards'

Other authors seem to have taken an opposite strategy: they start out not from LTS and their properties, but from societal events in their own right. Subsequently, they seek to identify the role LTS played in these events. They seem to 'reason backwards' from societal event to LTS.

This strategy may be illustrated by Mats Fridlund's study of the rise of modern Swedish nationalism. The canonical literature on nation building and nationalism observes – in a way we might call 'reasoning forward'—how expanding transport and communication systems tied regions together into countries and thus facilitated the shaping of national markets, political arenas and sociocultural homogenization entailed in the rise of the nation state.

Fridlund, by contrast, starts out from a well-known definition of nationalism in terms of seeking national identity, national unity and national independence. Then the Swedish version of it is specified: according to Swedish historians, late 19th century Swedish industrialists and politicians saw industrialization and technology as the means to restore Sweden's position as a European superpower. Having thus defined the societal effect, Fridlund investigates how Swedes actively mobilized LTS (or rather, elements of LTS, see below) to achieve and create these aspects of nationalism. For instance, Swedish technology (particularly from the telephony and electricity supply domains) was proudly presented at national exhibitions, helping to create a national identity of a technically able nation. This identity soon replaced the notion of Swedish technological backwardness and the old preference for things foreign. LTS interplayed with national identity in different ways, e.g. by references to Swedish history in the architecture of hydropower stations. Also with regard to national independence and unity electricity supply is a good example: the national government set up hydropower projects to achieve independence, and such projects might also serve national unity building. For instance, the first state hydroelectricity project started immediately after the (for Swedish politicians) traumatic loss of Norway in 1905 and could unite all political parties in a consensus.[31]

This strategy of 'reasoning backwards' can be found outside the LTS realm, most notably in historian David Nye and sociologist Claude Fisher's pioneering studies of users and uses of technology. Interestingly, they both take their cases from network technologies. Nye departed from the development paths of industry, the farm, the household and the city, and then identified how electricity was mobilized and used to reinforce these developments. US industry, concerned with scale increase, mobilized electricity to enable even larger scale production in the assembly line factory. In Denmark, by contrast, small and medium-sized enterprises seized electric drive to compete with large steam-powered factories.[32] Thus, electrical technology was given meaning in particular contexts of application, which do not follow logically and unambiguously from the intrinsic properties of the electricity supply system. Fisher made a similar point for telephony: when housewives seized the telephone to manage the family's social life, they created its 'social consequences' in ways unforeseen by the telephone companies. Fisher calls this strategy to study technology's social consequences 'user heuristics'.[33]

Intermediate Concepts

I think it is possible to identify a fourth strategy, which relates LTS and selected societal events by means of an 'intermediate concept'. Alain Gras' use of the concept 'space-time' can be interpreted in this way.[34] On one hand, Gras relates changes in the four dimensions in which lives are lived 'backward' to the development of multiple large technical systems. The creation of a new, modern space-time started with railways, the first LTS to create its own artificial space (bound to the tracks, not the landscape) combined with an information network (telegraphy). Enabling long distance coal transport, the train also illustrates the distribution of energy and thereby of technical vigour (*puissance*), previously tied to the mine-mouth or water wheel, throughout the new space-time. Electricity supply later radicalized this delocalization of technical vigour and made energy available at any place and any time by a pull of a switch. Third, telecommunication—to start with the telegraph—contributed to the dematerialization of this space-time: the world could be conceived of as a potential ensemble of connected points of simultaneous communication. Finally, air traffic illustrated how control of the flow was made the central element in the self-regulation of systems.

Yet this investigation of a new space-time is not a goal in itself. Gras relates it in turn 'forward' to societal changes of his interest, in this case changing power relations between man and nature, and between people mutually. For instance, while the new geography of LTS made possible worldwide production structures and the 'Global Village', it was also a means for imposing the Western model of society on the rest of the world, in the era of imperialism as well as that of globalization. In addition, citizens living within the new space-time (connected to LTS) were forced to adopt new behaviour, while those outside (such as the homeless) were cut off from the modern means of existence. Similarly, the social distance between centre and periphery was increased: the 'nodes' of the new networks were primarily situated in industrial and commercial centres that were already rich, and now became even richer relative to the areas in between—located in the 'mazes' of the network (often the countryside, which was rapidly depopulated). The concept of space-time thus connects analytically the development of network technologies with changes in the human and natural world.

Perhaps one can also include in this line of thinking Rosalind Williams' investigation of the simultaneous 'conquest of space' and 'loss of place', mediated by the development of LTS. On one hand the human preoccupation with LTS is traced to the Enlightenment ideology of circulation, while on the other hand it caused a sense of 'loss of place' that featured prominently in late 20th century technological pessimism.[35]

Second Order Large Technical Systems

Finally, it is useful to mobilize the notion of 'second order large technical system' in the investigation of consequences of infrastructural change. The concept was coined by the German sociologist Ingo Braun to denote a particular kind of material interlacing of different familiar, 'classic' or 'first order' LTS.[36] Braun is not concerned with the question of societal consequences. Rather, he aims to predict the internal development of LTS in the near future. As LTS are currently running out of space for expansion (air, ground and underground are rapidly 'filled up'), their future development may take the shape of material interlacing of existing material networks to create new functions or uses (*Vernetzung der Netze*). His most cited example is that of the European organ transplant system. The European organ transplant system since the late 1960s linked up medical nodes (like hospitals) with a host of LTS such as local road transport systems (mobilized by ambulance or taxi), regional, national and international air transport systems (mobilized by line and charter flights and helicopters) and local and transnational (radio-)telephone and data communication systems (comparing donor and recipient data over large distances) into one superstructure conveying flows of organs, people and information on a transnational scale. This so-called second order LTS, a superstructure constructed on top of 'existing first order LTS', is characterized by a rather 'heterogeneous' material network, as opposed to the 'homogeneous' networks of first order LTS. Contrary to the builders of first order systems, second order system builders typically create and control only a minor part of the elements in their systems. Their main task is to coordinate the interlacing of networks built and controlled by others. This type of system is not historically new (the postal system is an older example), but in Braun's view such systems emerged particularly during the last decades. This includes systems for collection and treatment of industrial and domestic waste, just-in-time production systems in industry, mass tourism, and a worldwide finance and exchange market system.

Other authors have picked up the concept in historical inquiries. Radkau uses the 'second order' feature to demarcate LTS in the 20th century from earlier generations of LTS and finds in the container revolution an important example.[37] Bucholz uses it to analyze an important historical event, the First World War. He describes the emergence of industrial mass warfare in Europe between the 1860s and 1914 as a second order LTS. This system was coordinated by war plans, including schemes for mobilizing railroads and telegraph systems to rapidly concentrate soldiers, ammunition and food supplies at battle locations. Originally developed by Prussia, the European superpowers all created their own systems, which anticipated each other and were increasingly interlocked. This resulted in a tightly coupled war system of pan-European size, in which the diplomatic sphere lagged behind the technical one and which could be triggered by a single event.[38]

Although not explicitly phrased as such by the mentioned authors, the concept of second order system building can be productive in the study of the societal consequences of infrastructural technologies for several reasons. First, while thematizing a certain type of LTS interlacing, the concept addresses by 'reasoning backwards' how what we might call 'institutional users'—like Eurotransplant or the military—(re)created their institutions by mobilizing the spatial dimension of multiple LTS. It is remarkable that user studies cited above (Fridlund, Nye, Fischer) focus on the societal implications of 'components' of infrastructural technologies. They investigate the uses of arc lights, streetcars, power stations, or telephones, rather than the society-wide networks that distinguish infrastructural technologies from other technolgies. The notion of second order system exactly emphasizes how specific user contexts may enrol not only functional artefacts, but also networks to produce certain events. The uses of networks may rank among the most important implications of network technologies. Manual Castells has argued that in present day Network Societies, social institutions (finance, work, production, crime) gained a network morphology by using ICT networks. The concept of second order system building allows us to go beyond his theoretical observation and trace empirically how this reproduction of networks throughout society actually took place.

Second, the concept suggests how new material superstructures and flows were constructed upon multiple infrastructures. As deep structures comparable to first order LTS, they also may generate (internal and external) societal changes of their own. Thus the concept suggests a new, more indirect level of societal consequences of infrastructural technologies. This indirect level can be accessed by the strategy of 'reasoning forward' from second order LTS to societal effects for individuals, groups, institutions, societies, nature, etc. For instance, one may suspect that the emergence and development of the organ transplant systems had consequences for the human self-perception, for instance through the 'brain-dead criterion'. Similarly, the development of the warfare system had consequences beyond its own sphere of combat; families were structurally dislocated and demographic structures of societies changed when a generation of men of military age died in the trenches.

Four Moments of Societal Change

Literature reviews usually serve the purposes and interests of the reviewer. The strategies extracted from the LTS literature can be rearranged into one framework of analysis geared to address the broad variety of societal implications of infrastructural changes, with due regard for their causal connection as well as moments of contingency, agency, or choice. Before proceeding, however, it is important to observe that this move is not necessarily uncontested in the field of technology studies.

Who's (Still) Afraid of Technological Determinism?

Sociological and historical technology studies have long been characterized by strong sentiments towards consequences studies of technical change. The 1970s' sympathetic and ethical scholarly concern to counter all forms of technological determinism, taken as a unidirectional and necessary relation between technology and society, made a deep imprint on these fields. By the mid 1990s Tom Misa could observe how massive engagement in demonstrating the contextual, social, or cultural embeddedness of technical change was accompanied by a nearly complete neglect of the reverse relationship, 'the intriguing question of whether technology has any influence on anything'.[39] When the question of 'social consequences of technology' was again placed on research agendas in the 1990s,[40] the way it was posed and answered was still conditioned by the determinism discussion. For instance, it is surprising to read how Fisher's above-mentioned pioneering inquiry into the uses of the telephone makes a major point out of rejecting a tradition called 'impact analysis'. Fisher accuses this tradition, which reasons from technical properties to social consequences, of an 'immanent determinism' and pleas that it 'ought to be abandoned', as should, indeed, the very word 'impact'.[41] The same goes for the second 'broad class of intellectual approaches to technology and society', which investigates congruencies between phenomena (linking for instance technical and social events to a *Zeitgeist* or dominant discourse) but seems unable to specify sharp causal relations. 'User heuristics' are the only approach that is both empirical, causal and denies the deterministic 'billiard ball model' of technical change and social consequences.

Fisher's phrasing may be extreme, but the tendency to allow some and reject other analytical strategies addressing societal implications of technical change is quite common. Bernward Joerges places 'reasoning from technical properties to social change' outside the field's accepted practice by claiming that the built environment puts up constraints to human behaviour 'only rarely and in the most trivial senses'.[42] A third argument against pluralism rejects methodological bifurcation: typical for 'mutual shaping of technology and society' approaches, Misa pleaded to 'retrieve sociotechnical change from Technological Determinism' by 'healing the methodological bifurcation' between 'constructivist' micro and 'determinist' macro perspectives, in a synthesising effort with its privileged strategic research site (in his case, institutions intermediating between the macro and the micro).[43] Perhaps the potential tension between pluralism and fears of technological determinism is most visible in the so-called social shaping of technology (SST) field. A recent review tells us that this field celebrates pluralism of approach, but simultaneously that membership of the 'broad church of SST' requires sharing a 'basic idea' of 'fundamental opposition' to technological determinism, meaning that the analysis should show how 'technical change ... is always part of a larger *sociotechnical* transformation' (italics in the original).[44]

As an imaginary adversary, technological determinism is alive and kicking and it does seem to prevent a number of respected authors from addressing the variety of technologies' societal implications that this paper would like to bring into vogue. Mutual shaping studies (including the canonical LTS approach) rarely look beyond the sociotechnical construction process, and claiming user heuristics as the promised approach Fisher in fact only investigates those consequences of telephony that have his special interest: 'consequences for—and created by—users', and even a particular type of users: 'individuals [dealing] with family, friends, and themselves in daily life'.[45] Changes in institutions, societies or nature that may not be shaped by users remain invisible.

It is not my intention here to engage in a theoretical debate on technological determinism or the authors that are supposedly determinist.[46] The ongoing discussions in the field, however, do place the burden on any framework of inquiry addressing technology's societal consequences to show how its suggestions relate to critiques of technological determinism, that is, to show moments of contingency, agency and choice as well as causal relations.

Four Moments of Societal Change

With the strategies and concepts in play, one can juxtapose different analytical strategies to investigate infrastructure-related societal changes. These analytical strategies make visible at least four distinct moments where such changes are produced. These moments may be causally related, in the sense that the margins for later implications may be defined in earlier stages. Still, each moment may also add contingencies, agency, or choice. Thinking in terms of these moments may help transcend the positions and discussions presented in the first section.

These four moments are illustrated below with the intriguing and complex case of Dutch waterway building, the societal implications (in which, it should be reminded, we include natural as well as social changes) of which were enormous, both immediately and remote, as canal systems built a thousand years ago continue to affect today's society in multiple ways.

Sociotechnical System Building in the Construction Phase

The canonical LTS approach that follows system builders as they manipulate and juxtapose technical and non-technical elements into a sociotechnical whole is geared to access a first moment where infrastructure-related societal changes are generated. The sociotechnical construction process, as we saw above, involves the shaping of influential and obdurate non-technical 'elements', while system builder values may be inscribed in the material layout.

In the case of Dutch waterways, the reclamations of extensive peat bogs in the 'Low Netherlands' (covering more than half of the territory of present country) between the 9th and 13th centuries AD were entangled with the founding of rather autonomous settler villages. These were originally set up in the North by settler initiative, but later copied by Western dukes or counts in their region. Increasing challenges of drainage and dyke building were accommodated within the settler village framework. However, from the late 12th century dam and sluice building, serving perhaps 20 villages or more, challenged the organizational capabilities of the settler villages and coincided with the institutional invention of what later would be called 'water boards'.[47] Comparable to the 19th century's railroad companies, 20th century electricity companies, or present ICT companies, these became a powerful player in the Dutch social and political landscape. Today they still constitute a level of local government in parallel to municipalities.

As to the embedding of values into the physical design of infrastructural technologies, these canals were initially designed to reclaim and cultivate land, and that is what they did—at least in the short term. To some extent, there were conflicts on the design of these canals: water boards were dominated by large landowners, who prioritized water control. The canals might be constructed in ways that collided with uses by other groups, for instance when dam building obstructed inland navigation and fishing.

Unexpected Implications of Intrinsic System Properties

Second, the strategy of 'reasoning forward' from the intrinsic properties of network technologies to societal events gives access to a second layer of societal implications, which may be external to the sociotechnical construction process and beyond the control of the actors participating in this process.

This strategy is more controversial in relation to modern technology studies. In reply to *a priori* rejections of any strategy reminiscent of technological determinism, it is worthwhile observing that deterministic cause-and-effect relations do exist between infrastructural change and natural environment. The above-mentioned local reclamations of the 9–13th centuries not only made the Netherlands inhabitable, but also gave oxygen access to organic material that subsequently decomposed and produced a soil subsidence of several meters. Peat digging and a rising sea level worsened the situation. Floods became endemic, a mostly closed coastline was perforated and the characteristic south western delta, the large inner sea Zuiderzee (the now dammed IJsselmeer), and several other large inner lakes were created. This happened behind the backs of the system builders in a process spanning centuries; the causes of this process have only been uncovered by scientists in the last decades of the 20th century.[48] The effects, nevertheless, were huge, and ought not to be missed by any study on societal implications of waterway building.

Even if relations between technical properties and societal events were not of a strictly deterministic nature, the strategy should not be excluded. For instance, it has been argued that the revolutionary passenger transport network of horse-pulled barges, largely through newly constructed canals, which represents one of the first mass transportation networks in pre-industrial times, came to define a new 'time frame' of the Dutch Republic.[49] Also, access to the waterway system heavily influenced the shaping of the urban system of the Dutch republic, the leading cities of which were favourably situated at junctions in the waterway system. Clearly, such events were not deterministic—if determinism is taken to be a unidirectional and necessary relation between technologies and societal events. In the social world, such relationships hardly exist. To dismiss such observations as implying a 'billiard ball model of technology and social change' may result in throwing the baby out with the bathwater. Dismissing the supposed determinism of a wall erected to keep people out, Joerges asks, 'what if one is armed with a tank?'.[50] However, the simple fact is that most people do not have a tank. They will just adapt to the wall. The 'soft determinism' of such technologies may be better described as a 'force field' rather than a 'billiard ball', as Heilbroner has suggested.[51] The same applies to the mentioned examples from the case of waterways.

Institutional Users and Second Order System Building

Within the margins defined by the technical possibilities and constraints identified at these first two moments of generating infrastructure-related societal changes, the strategy of 'reasoning backwards' may expose a third moment, when users enrol network technologies to shape structures of their own. Most interesting is perhaps the construction of new networks or 'second order large technical systems' by institutional users, who mobilize and possibly modify existing network technologies to create new networks and flows.

The shaping of food chains is a good example.[52] In the Netherlands, the food infrastructure largely followed waterway infrastructures until well into the 19th century. On one hand, regions connected to the exceptional inland navigation system (which involved scheduled freight transport between cities, and between cities and surrounding villages) were integrated in a global economy via (amongst others) the Amsterdam staple market and the global navigation networks of the Dutch East and West India companies. This economic system largely covered the so-called Low Netherlands. On the other hand, higher grounds—only accessible by road—remained relatively isolated and local food circulation dominated. This co-existence of global food chains and local food flows disappeared in the 19th and 20th centuries, in which inland navigation networks were integrated on a national level, railroad networks were added to the transport landscape, and nationally integrated road networks were densely branched. On this material basis actors in the food sector, the institutional users under scrutiny here, organized nationally integrated food chains. By the 1960s, a standardized assortment of foodstuffs had become available in every remote corner of the country to all social groups.

How did this come about? If one follows the actors in the food sector, one finds them constantly concerned with mobilizing transport networks. To take an example from the production side, the new dairy factories of the 1890s counted factory machinery as well as boats for milk jugs under its 'factory equipment'. These were necessary ingredients to connect the factory into the milk flow. Similarly, the wave of concentration of many small into fewer very large dairy factories from the 1960s coincided with innovations such as the refrigerated milk transport truck. New means of transport allowed coverage of larger supply regions, and to make the new system economically feasible, daily traffic between farms and factory was cut down to twice per week. This tied the new system to refrigerated transport and the related innovation of refrigerated cooling tanks at the single farm. The dynamics of this system were exposed when farmers refused to invest in cooling tanks and the sector was caught in the so-called 'tank war' of the late 1970s, which culminated in the taking hostage of a dairy board by farmers wishing to preserve their milk jug system.

Similar examples of the importance of transport in changing food chains can be found on the distribution side; from the 1920s the large retailer Albert Hein (as Ahold currently a worldwide player) set up a so-called 'satellite system' connecting a central warehouse to local shops by means of a company truck fleet complete with company mechanics. When it opened its first supermarkets some four decades later, the parking place was recognized as an essential element—to couple the new store into the food chain by road connecting to the consumer. Currently, a new data system is being set up connecting supermarket checkouts to the central warehouse, so that supermarket stocks can be centrally monitored and refilling improved.

Consumer Choices

Finally, as 'intermediate concept' such second order systems as the food system provide a causal link between infrastructural technologies, on one hand, and societal implications of their own, on the other. Thus we reach a fourth layer of still more indirect implications, of which the development of Dutch food and meal patterns is a good example. In the fragmented food system of the early 19th century, meal and food patterns varied by region. The national integrated food chain of the 1960s, however, was accompanied by a remarkable event that Dutch food historians have dubbed the 'unification of the Dutch meal'.[53] Dutchmen of all social layers everywhere in the country tended towards a pattern of three meals per day, two cold bread meals and one hot dinner, consisting of three courses: soup, a main dish of potatoes, vegetables, and a (by foreign standards) ridiculously small piece of meat or fish, and a desert. This homogenization process did not follow automatically from the growth of infrastructures or even the growth of the food chain, as is often implicitly assumed in nation building studies. A range of mediators, including advertising agencies, home economists, cooking advisors and state research institutions worked very hard for many decades to influence consumer behaviour. Motives ranged from profit to national health and support to national industries, but in this particular period in Dutch history, characterized by cooperation between government, consumer associations, and industry, these concerns could push consumer choices in a similar direction. Never before or after have consumers chosen so unanimously from the available assortment.

We may thus make visible a causal line from infrastructural technologies, via the shaping of a food chain by multiple actors in the food sector, via consumer choices affected by other players to changes in what and when people eat. While being causal, this chain of events includes a number of identifiable moments of contingency, agency and choice. Things might have worked out differently.

Indeed, eating habits changed again after the 1960s. From a Dutch perspective, food historians observe a 'fragmentation' of previously uniform meal and food patterns. This did not mirror a breakdown of road, rail, water and data infrastructures. On the contrary; transnational infrastructural connections were improved and food chains increasingly operate on transnational scales. Organizers of new food flows include big players as Nestlé, Philip Morris and Unilever, who supply large shares of today's European supermarket assortments.

It is the expansion of the food system that enables a reproduction of fragmented food and meal patterns throughout the Western world. Consumer groups and their choices have differentiated and the food support structure caters for their different wishes. For instance, in New York as well as in Paris or Eindhoven new forms of work have given rise to the eating habit coined as 'grazing'; modern workers exchanged fixed mealtimes for picking-up small snacks whenever possible to assemble their daily needs.[54]

Conclusion

The pluralist framework sketched above mobilizes the study of sociotechnical construction processes, intrinsic technical properties, uses and the intermediary role of superstructures as simultaneous effects and causes. These potentially contradictory research strategies can link the development of network technologies causally to at least four moments where infrastructure-related societal effects are generated. As the cases show, these might pertain to very different areas of life. Moreover, they might occupy a particularly long time span.

It is urgent, therefore, that assessments of infrastructural projects are not caught in seductive utopian (or dystopian) discourses that have surrounded infrastructure building for centuries. The framework suggested here is intended to transcend these debates and liberate the imagination. Notably, much more research to the multiple implications of infrastructural changes is needed. It would be unfortunate if a lock-in on resistance to technological determinism continues to prevent such wide-ranging inquiry.

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