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Large Technical Systems

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Background

The notion of Large Technical Systems (LTS) refers both to an *approach* to understanding and analyzing sociotechnical change, and to a *class of phenomena* – large infrastructural and production systems – which are particularly suited for analysis by an LTS approach.

LTS thinking finds its roots in the American historian Thomas P. Hughes's book *Networks of Power: Electrification in Western Society 1880–1930* (1983). In the late 1980s, the LTS approach was positioned among the promising "new directions in the sociology and history of technology" next to the Social Construction of Technology (SCOT; see Chapter 15) and Actor-Network Theory (ANT; see Chapter 64).

Simultaneously, an LTS literature emerged to investigate large infrastructure and production systems. Since then, the conceptual framework and the empirical range of inquiry have steadily expanded.

LTS-informed work is best-presented not as a coherent theory in a strict social science sense, but rather as comprising a variety of narratives, concepts and research strategies that can inspire inquiry. These are usually guided by two original concerns.

A first important original concern was to criticize and transcend the customary focus upon artifacts or machines in history and sociology, routinely investigating the lightbulb, locomotive, motorcar or assembly line as loci of technological change and harbingers of major social changes. Such artifacts, however, were only the most visible of many interacting elements that jointly formed entire "systems" for electricity supply, transportation, or industrial production. In electricity supply systems, for instance, the designs of steam engines, generators, distribution networks, and consumer appliances were mutually adapted and aligned into one functioning whole. Such systems constitute true frontiers of twentieth-century technical change as well as important "deep structures" in modern societies. Therefore, in LTS research, systems, not their most visible elements, form the primary unit of inquiry.

A second original concern is that explaining the development, functioning and societal implications of such systems demands understanding their *sociotechnical* nature (a concern shared with SCOT and ANT). In the case of electricity supply systems, design properties also interacted with non-technical system elements as company structures, financial possibilities and obligations, negotiated government concessions,

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and consumer practices. Traditional analytic categories apriori separating the "technical," "political" and "economic" obscure such sociotechnical intertwinement. Worse, they may superimpose analytical boxes that obscure the sociotechnical fabric from view. Hughes and others therefore developed alternative concepts to inquire how the sociotechnical fabric is woven, how it works, and how it intertwines with broader societal changes.

These concerns inspired historical narratives of the development of specific systems and the history of large technical systems as a category *sui generis*; the development of strategies for building and managing systems; and the intertwinements of LTS development and the shaping of cities, nations and regions. For reasons of space, I shall here focus on the LTS *approach* and key concepts informing the inquiry of LTS dynamics and its societal implications.

Concepts for Examining LTS Dynamics

As the most common denominator, studying technologies from an LTS perspective, whether electricity supply, uranium supply chains, steamboats, or weapon production systems, means bringing into vogue their systemic and sociotechnical aspects. Beyond that, there is no consensus on defining words like "large," "technical" and "system." It is true that early LTS studies often presupposed centralized control over all system elements and excluded anarchistic systems like road and water transport. Later studies, however, examined exactly self-regulation and coordination mechanisms in "loosely–coupled" large technical systems. Likewise, some authors have defined large technical systems by function (communication, transport, energy supply), while others investigated challenges and problems due to their multifunctionality (again, particularly in water-based and road systems).

A number of concepts aim to spotlight the systemic and sociotechnical character of LTS development. Most of them were first introduced by Hughes. Regarding overall system development, Hughes identified a "loosely defined" pattern of LTS development with "overlapping yet discernible" phases. In an *invention phase* a new technological system emerges around radical inventions. In a *development phase* this nascent system is adapted to economic, political and social characteristics needed for survival in the "use world," typically at test sites. An *innovation phase* adds further system components relating to manufacturing, sales and service facilities, enabling the system to enter the market. In a phase of *competition and growth* the system expands and adapts in competition with rival systems. In a *consolidation phase* a system has acquired so much "momentum" that it is difficult to change, creating an appearance of autonomy from its environment. A *technology transfer phase* may occur at any time during a system's history. Here it is exported to different environments, for instance different countries, and adapted to new natural, social and technical contexts. Finally, other authors soon added a phase of *stagnation* or decline, which was lacking in Hughes's original publications.

Several concepts specify driving forces behind such system development. First, the concept of *system-builders* brings human agency into the analysis of sociotechnical system development (which was ignored in earlier system theories, most notably general systems theory). The concept refers to individuals and (later) organizations that mold and align technical and non-technical elements into a sociotechnical whole; they do the sociotechnical weaving. The concept suggests studying key actors not as heroic inventors, but as dedicated builders of sociotechnical systems: Thomas Edison was not so much concerned with "inventing" the lightbulb as with designing and selling entire electricity supply systems, which demanded simultaneous work on a commercial vision, contracts with local governments and financiers, setting up new companies, marketing, and new generator, distribution network and lightbulb designs.

Often, system-builders work by identifying *reverse salients* – elements lagging behind and restraining total system development – and translate these into *critical problems* that may (or may not) be solved. Such reverse salients and problems can be of a technical or non-technical nature; system-builders engage in *trans-disciplinary problem-solving*. Furthermore, different types of system-builders dominate different phases of system development. *Inventor-entrepreneurs* such as Edison are crucial during invention, development and innovation, while *manager-entrepreneurs* (e.g. Henry Ford setting up his automobile production system) preside over the growth phase. *Financier entrepreneurs* and consulting engineers are the main players in the consolidation phase. System-building approaches also varied in time: *modern system-building* refers to top-down hierarchical organization structures and micro-management in the pre-Second World War period, while *postmodern system-building* of the 1990s reflects counterculture values such as horizontal organization and participative system-building – giving stakeholders access to the design process. *Ecotechnical system-building* refers to restoring and redesigning natural systems like river or forest systems.

Hughes's original concept paid scarce attention to one important human attribute – conflict. It emphasized how system-builders manipulated and aligned system elements in a rather top-down fashion. Later studies, by contrast, often examine system-building as a game involving many actors, full of negotiation and possibly conflict, producing winners as well as losers. They study system-builders as a methodological move to gain access to the systemic, sociotechnical and contested character of sociotechnical change.

Other concepts point at structural drivers of system development. The concept of *technological style* expresses how the designs of systems and their interrelated technical and non-technical elements change when transferred to other social, natural or technical environments.

By contrast, the concept of *momentum* articulates the apparent autonomy of mature large technical systems, resisting pressures for change. This physics metaphor suggests a "mass" (again, in terms of interrelated technical and non-technical elements as invested capital, actor commitment, employment, user habits, etc.) traveling with a certain "speed" in a certain "direction" (e.g. geographical expansion or scale increase). The concept is broader than comparable concepts of "path dependency" and "lock-in" in the economics of innovation. Large-scale electricity supply had reached considerable momentum by the 1930s; the trajectory of scale increase proved difficult to change since.

Related concepts explaining growth and momentum address economic performance. Next to economies of scale and scope, Hughes introduced the concepts of *load factor* and *economic mix* from the electricity supply world. A high load factor denotes a stable system load, allowing better usage of the available machinery and thus a quicker return on investment. An economic mix denotes the pooling of production facilities with different characteristics so as to optimize production costs at any given moment.

Later research has further nuanced these insights. In particular, Arne Kaijser and his Swedish collaborators have developed a wealth of concepts differentiating between systems with different technical, geographical, economic and institutional properties, with due implications for their development patterns. For instance, systems with artificial or *specific links* like railroads or electricity supply networks are less easily changed than systems using *nature-based links* like maritime navigation or air transport, or already *existing links* like the postal system. In the Baltic countries after the transition, air connections were predominantly reoriented to the West, while train and electricity connections remained focused on Russia and the Ukraine. Systems vary geographically on their local, provincial, national or international scale and their representation by dots (like self-generating electricity units), lines (like railroads) or fields (like radio systems). Economic criteria include financing and pricing methods, while institutionally systems diverge on forms of government control and forms of cooperation between key actors like operators, equipment suppliers and users.

Much work has been done on the issue of system stability and change, particularly in the light of a desired transition toward more sustainable transport and energy systems. If mature large technical systems are characterized by a large momentum and resist change, only extreme external conditions like warfare, oil crises, environmentalism and government interference may change the development trajectory. The policy implication is that, to assist change, policy-makers should set up protected spaces or "niches" where new systems can be invented and grow, protected from the established system until they are able to compete. Another strategy is to generate innovative views on future system developments in the minds of the main stakeholders using participative technology assessment methods. Current policy tools for sustainable technological development as Strategic Niche Management and sociotechnical scenario development partly lean on LTS insights.

Some authors, however, dismiss the assumption that mature systems cannot change. Closed systems can open up and adapt to new internal and external circumstances. In this vein, ongoing work on system innovations is developing a taxonomy of transition paths originating either from within or outside existing systems.

Societal Implications of LTS

LTS authors see large technical systems as "deep structures" shaping individual and social life. Conceptualization of LTS's societal (in the broadest sense) implications has been limited, though, mainly because of a general concern to steer clear of Technological Determinism. Only recently it was commonly accepted that the technological shaping of society can be investigated in non-determinist ways.

The notion of sociotechnical system-building, of course, already encourages inquiry of several LTS-related societal changes, namely those that are part and parcel of the sociotechnical construction process. For instance, electricity supply systems made light and power omnipresent, Swedish or Norwegian hydropower systems secured national energy independence, and the Australian interstate power grid should break the state-owned utility monopolies that kept prices up – and break coal-miner strikes that were organized at the state level.

Other approaches bring into vogue indirect, often unanticipated and long-term societal changes related to LTS development. Once built, *users* may use large technical systems in multiple, sometimes surprising ways. Users, too, are agents of indirect LTS-related societal changes. Large-scale industries used electric drive to design even larger factories; medium- and small-size industries, however, employed electric drive to improve their competitive position relative to large factories. Households helped shape the meaning of electricity and gas supply systems in the home. *Institutional users* such as the military, the food sector or the health sector built their own systems (so-called *second-order large technical systems*) for defense and warfare, food supply, and organ transplantation on top of existing transport and communication systems.

Finally, some changes follow the *intrinsic properties* of large technical systems. Electricity supply and automobility systems initially greatly reduced urban reduction, but in the long run their massive diffusion created new forms of regional and global pollution such as acid rain and the greenhouse effect. System properties also may enhance new consciousness and mental spaces; space exploration systems inspired a rediscovery of a fragile blue planet Earth and the concept of the biosphere, train travel interfered with perceptions of the landscape, etc. Such LTS-related changes may have a deterministic character, whether as a natural science cause-and-effect relation (effects on the natural environment) or as a "force field" favoring some changes above others (in the social world), but remain too important to be excluded from critical analysis as undesirable "Technological Determinism."

References and Further Reading

Coutard, O. (ed.) (1999). *Governing Large Technical Systems* (London: Routledge).

Coutard, O., Hanley, R. and Zimmerman, R. (eds) (2005). *Sustaining Urban Networks: The Social Diffusion of Large Technical Systems* (London: Routledge).

Elzen, B., Geels, F. and Green, K. (eds) (2004). *System Innovation and the Transition to Sustainability: Theory, Evidence and Policy* (Cheltenham: Edward Elgar).

Hoogma, R., Kemp, R., Schot, J. and Truffer, B. (2002). *Experimenting for Sustainable Transport: The Approach of Strategic Niche Management* (London: SPON).

Hughes, T. P. (1983). *Networks of Power: Electrification in Western Society 1880–1930* (Baltimore, Md.: Johns Hopkins University Press).

Hughes, T. P. (1987). "The Evolution of Large Technological Systems," in W. E. Bijker et al. (eds), *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology* (Cambridge, Mass.: MIT Press), pp. 51–82.

Hughes, T. P. (1998). *Rescuing Prometheus* (New York: Pantheon).

La Porte, T. (ed.) (1991). *Social Responses to Large Technical Systems: Control or Anticipation* (Dordrecht: Kluwer).

Mayntz, R. and Hughes, T. P. (eds) (1988). *The Development of Large Technical Systems* (Frankfurt: Campus).

Summerton, J. (ed.) (1994). *Changing Large Technical Systems* (Boulder, Colo.: Westview Press).

van der Vleuten, E. (2006). "Understanding Network Societies: Two Decades of Large Technical System Studies," in E. van der Vleuten and A. Kaijser (eds), *Networking Europe: Infrastructural Integration and Disintegration* (Sagamore Beach, Mass.: Science History Publications).