Day 5: Thomas Hughes's Technological Systems

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HOT Handout Technological Systems

"THOMAS HUGHES' TECHNOLOGICAL SYSTEMS"

(a summary by Rob Martello)

Historian of Technology Thomas Hughes wrote an article titled *The Evolution of Large Technological Systems*.[1] This article defines technological systems, explains a typical path by which they evolve, discusses different types of individuals who facilitate this evolution at different stages, and also explains several related concepts. Would you like to hear about these different ideas? No need to answer, because, sadly, you have no choice. Please note that Hughes focuses his theory upon large technological systems, and many of his case studies draw from the mid 20th century -- electricity networks, automotive manufacturing and distribution, etc. As you read this, think about whether we can apply this theory to technological systems of different sizes today – does this require updating? Hmmmm…[2]

WHAT IS A TECHNOLOGICAL SYSTEM?

"Technological systems contain messy, complex, problem-solving components." Thus Hughes begins his essay. In fact, he highlights five types of components of what he considers a system:

1. Physical artifacts (e.g., a generator or transformer)
2. Organizations (an investment bank or utility company)
3. Scientific components (books, expertise)
4. Legislative artifacts (laws, lobbyists)
5. Natural resources (coal mines)

All components in a given system are interrelated: alter one part and you alter many others. In general, the system attempts to function within a climate of stability and order, and parts of the system are often judged by their efficiency and output. Hierarchy is also a common structural element of systems.

With all this talk of components, we seem to have sneakily avoided defining a system. Hughes says a system will "solve problems or fulfill goals using whatever means are available and appropriate; the problems have mostly to do with reordering the physical world in ways considered useful or desirable, at least by those designing or employing a technological system." The definition of a system introduces

Best for whom?

[1] This essay is contained in *The Social Construction of Technological Systems*, edited by Wiebe Bijker, Thomas Hughes, and Trevor Pinch (Cambridge: MIT Press, 1987).
[2] Hmmmm.

some of the same challenges and concerns raised by the definition of technology. A system is clearly a larger entity than a technology, because a system employs technologies along with other components in an integrated attempt to achieve its ends. A light bulb is a *technology*, as is a dynamo. A lighting *system* would include manufacturing elements, generators, distribution lines, an installation and maintenance strategy, sales staff, a billing department, lawyers, research and development teams, lobbyists, and many other elements. So we conclude that a technological system is a complex entity intended to solve problems by making use of one or more technologies, ideas, business and financial components, and other resources.

connect: Artifacts have politics?

In a noted quote, Hughes explains that systems are "*both socially constructed and society shaping.*" This means that social considerations play an integral role in the creation of a system, the system has visible and subtle impacts upon societal and cultural practices, and the system constantly responds and reacts to social inputs.

Systems exist in a societal context… and also in an environmental context. Hughes defines the environment very broadly as "intractable factors not under the control of the system managers." These "intractable factors" include the natural environment (nature) as well as other influences (government, society, etc.). Correspondingly, growing systems attempt to incorporate parts of the environment into the system, thereby reducing uncertainty. For example, a small manufacturing endeavor might consider coal a part of the environment – the system therefore has no control over the availability or cost of this component of production. A large technological system might purchase its own coal mines to ensure a guaranteed supply of this vital resource. Replace "coal" with "government" and we have a really interesting scenario, with many real-world implications. Systems will always have inputs and outputs that link them to different aspects of their environment.

Systems have human components as well. Many system builders attempt to minimize the degrees of freedom (or as Hughes says, "minimize the voluntary role") of the human components of systems via practices such as bureaucracy, deskilling, and routinization (do you know what these terms mean? How are they relevant?). Human beings usually add unpredictability to a system, which is often undesired from a management/strategy perspective that favors predictability. This is not universally true, however. People serve the vital role of completing the feedback loop between the system's aims and actual performance, largely by catching and correcting errors, and by continually making operational adjustments.

System Evolution

Hughes postulates a five-step evolutionary process followed by most systems: Invention, Development, Innovation, Transfer, and (the last one has three parts) Growth/Competition/Consolidation. He clearly states that this progression is never orderly or simple or neat because system stages overlap and backtrack with a mischievous whimsy that is truly dazzling to the noggin.

Furthermore, each stage of the system emphasizes the role of a specific type of system-builder, a leader or problem solver who usually makes the most critical decisions at each point. These leadership types will be discussed below. And thus, without further ado, it is my deepest honor to present to you, right at this precise moment, this exciting rendition of... the five phases of technological systems.

1. Invention

Hughes lays out two types of invention: radical or conservative. **Radical** inventions represent the hallmark of the entire "invention" phase of a system, because radical inventions inaugurate new systems by creating new technologies or other artifacts that do not contribute to any existing system. "Radical" means "new and revolutionary" in this case. A **conservative** invention, in contrast, is a development that improves or expands an existing system. (Does this remind you of normal and extraordinary science? This is not a coincidence: Hughes was inspired by Kuhn's paradigm theory when he formulated this idea.)

History contains many examples of independent, professional inventors who concocted radical inventions that inspired technological systems: for example, Alexander Graham Bell and the telephone, Thomas Edison and the electric light, etc. Academics also serve as wellsprings for radical inventions, either by inventing them outright or by laying groundwork that inspires invention.

Not always true: iPhone, Xerox PARC, Nintendo

Inventors in the employ of a large company (i.e., not the independent ones mentioned above) are often tied to the mindset of the company and as a result focus on conservative instead of radical inventions. Company-employed inventors have more constraints upon their work as well as a great incentive to leverage their company's existing scientific and technological infrastructure.

Note that an invention is not always an attempt to start a new system even if that is what eventually happens. Inventions often take the form of attempted improvements over earlier inventions or solutions to problems. These attempts might fail, or might blossom out of control, and in either case the inventor might recognize that the old system has become more of a hindrance than an asset. See the "reverse salient" concept below for more on this aspect (or don't see it – I'm not pushy).

Hughes also examines some of the challenges of the invention phase. Funding is often an issue, especially for independent or nonprofessional inventors, which partially explains the importance of academic research. Funding limitations are mitigated by patents, a legal mechanism for converting ideas into (intellectual) property. Hughes also muses about the actual process of invention – the so-called "Eureka!" moment of inspiration, but does not discuss this in detail.

The key figure during the invention phase is the **inventor-entrepreneur**. Hughes defines an **entrepreneur** as a "**system builder**." Therefore, an inventor-entrepreneur is an individual bridging the technical and non-technical aspects of systems, someone who can create something new and visualize its modification and expansion and eventual development. This is a useful segue into the next section, so please crack open a delicious iced tea (or other beverages, pending approval from a 2/3 supermajority of the Department of Student Life) and let's forge onwards.

2. Development

The **inventor-entrepreneur** also prevails over the development phase of technological system growth. Development is the step by which an invention begins to transform into a technological system. This involves different procedures such as testing, expansion, redesign, and additional invention.

The initial invention becomes *socially constructed* at this point, meaning it is imbued with "economic, political, and social characteristics that it needs for survival in the use world." An initial invention might be a model, an idea, or a prototype – brilliant in theory but questionable in practice. A "developed" invention (i.e., one that has completed this development stage) is able to function and solve problems in a real world setting because it explicitly takes real world factors into account. For example, the first light bulbs produced light for a brief time before they burned out, required intensive hand crafting, and used expensive components -- they were great as a proof-of-concept but were not practical. Later light bulbs had cheaper and more reliable filaments and relied upon standardized manufacturing techniques.

The radical invention is often aided by a complement of conservative inventions during this stage. These conservative inventions are solutions to practical implementation challenges (technical, economic, organizational, psychological…) and might represent additional patentable concepts; in fact, this is often the case.

Hughes mentions that scientists often display a greater capacity for invention, while engineers are more adept at development. Do you agree with this? Why or why not? What might this imply about the connections or differences (real or perceived) between science and technology?

3. Innovation

Innovation represents the actual creation of a technological system. This step combines all components into a coherent network that begins functioning. The innovation stage introduces a large number of organizational challenges, and therefore the principal individual problem solver here becomes the **manager-entrepreneur**. This might be the same individual who presided over the inventor-entrepreneur stage, but is often a new person with different skills and interests, someone who shifts the emphasis from planning to implementation.

A manufacturing system might require production, sales, marketing, and service components at this point. Thomas Edison offers a good example: by 1882 he had formed a web of companies to address different aspects of the lighting network, including a financing and licensing company, urban utilities, a machine works company to manufacture dynamos, an electric tube company, and a lamp manufactory.

As mentioned earlier, a major goal at this point is increasing the size of the system by reducing the size and impact of the uncontrolled environment.

4. Transfer

Transfer is an interesting step that can occur at different points in a system's growth process. Transfer is the process of moving or expanding a system into a new location. Recall the earlier statement about how these stages do not necessarily follow one another in a linear manner. Transfer is particularly likely to take place in parallel with other steps, or at various points.

When system builders first design a system they take into account the conditions and climate in their initial location, including factors such as the existing political (legislative), economic (market), or geographical (resource, transportation…) conditions. The system is given survival characteristics based on its first environment. The transfer phase describes the adaptation of a system for successful functioning in a new location or environment.

Interestingly enough, Hughes contends that the inventor-entrepreneur, the manager-entrepreneur, or both might supervise the transfer stage. The challenges at this point span many areas.

5. Growth, Competition, and Consolidation

Finally, systems grow and encounter other systems. Hughes refers to a technical motivation that encourages systems to grow: the desire for a high **load factor,** which is the ratio of average output to the maximum output of a system. This is another way of saying that systems want to efficiently utilize their capacity.

System builders also seek diversity and an economic mix by producing a range of different products or by reaching different markets. Diversity offers stability and security against local or temporary problems that affect demand for a product.

As one might imagine, continued growth causes a system to encounter other systems in competitive or collaborative ways. Hughes does not describe this process in detail – a case-by-case approach seems warranted. Perhaps YOU will someday publish an award-winning paper on this subject!

Key Concepts

The final section of this summary outlines three valuable concepts used by Hughes to explain the growth and behavior of technological systems: technological style, reverse salients, and technological momentum. These concepts have been used in a variety of contexts outside of technological system theory, so please consider wider applications as you read them.

Concept: Technological Style

Technological style is tied to the above discussion of technology transfer. Hughes makes the point that "adaptation is a response to different environments and adaptation to environment culminates in style." The concept of a prevailing architectural or artistic style in a certain time and place can be applied to technologies as well.

Technological style carries an important message: system builders can act with creative freedom. There is no single best way to design a system, but "best" depends upon the standards of the designer or viewer.

Best for Whom

Style can be seen as a reaction to natural geography, to regional or national history, and to political practices and ideology. One example of technological style involves the design of power systems in 1920s-era London and Berlin. London had more than fifty small power plants while Berlin had about six big ones, reflecting different emphases upon centralization and authority (Berlin) or the importance of autonomous local government (London). Neither style can be judged as "better" in terms of efficiency or total output.

Concept: Reverse Salients

Reverse salients are "components in the system that have fallen behind or out of phase with the others."

For example, suppose that Rob, Luke, and Jaclyn decide to start a novelty note card business. Rob folds the paper into beautiful origami shapes, Luke adds a delightful whisper of glitter and a whimsical misting of perfume, and Jaclyn writes pithy inspirational messages on each one. Business booms and orders increase. Rob discovers that he can fold ten papers an hour, while Luke artfully completes 20 in the same time and Jaclyn plows through 30 without batting an eye. Rob's stage of production is clearly the *reverse salient*. Until he develops a way to improve his part of the process, his industrious colleagues will be unable to work to their fullest capacity or increase their own efficiency.

Technological systems often concentrate their entire problem-solving resources upon the largest reverse salient at any given time, and therefore incrementally improve their performance. Reverse salients can be technical, organizational, economic, or more than one of the above. Therefore, problem solvers holding different skills (inventors, engineers, managers, financiers, lobbyists, etc.) are needed at different times.

If a reverse salient cannot be corrected within an existing system, the problem might eventually call for a radical invention that might produce a new and competing system.

Concept: Technological Momentum

The concept of technological determinism implies that technologies gain autonomy. Technological momentum is a correction to determinism.

Physical momentum equals mass times velocity (p = mv).[3] A large technological system develops a mass of technical and organizational components, and these components possess direction, goals, and a rate of growth that imply velocity. Large systems begin moving with a momentum that imparts an inertial resistance to sudden change. For example, a manufacturing system that has invested heavily in certain types of production equipment and the personnel to operate them is unlikely to seriously consider alternate manufacturing strategies.

Technological momentum is an especially pressing issue in larger and older systems that have alliances with financial or political institutions. These technological systems have a large number of stakeholders

[3] Yes, this is a formula.

with vested interests in the survival and success of the system, thereby allowing the system to modify its economic or regulatory "environment" in ways that help it prosper. In the Hughian sense, therefore, this type of environment has become a part of the system since it is now controllable. Think of the many large corporations that can threaten competitors or lobby governments for subsidies or protective policies. These companies use their momentum to continue doing business in the manner to which they are accustomed, and can often get away with older methods when smaller companies would have to adapt to changing conditions.