# TECHNOLOGICAL CHANGES AND TRANSPORTATION DEVELOPMENT

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## Contents





## Summary

This discussion emphasizes the ways transportation innovations and technological improvements increase options available to users. As the variety of services increases, users improve the ways old things are done and engage in new activities. Thus transportation innovations and technology development enable social and economic progress. The challenge is to improve the future by increasing options available to users. This broad challenge is in response to sustainability issues posed as social, economic, and

physical environments change and affect life support systems.

The task is easy to state. But a look back and around reveals disjoint institutions and actors. Actors include (1) suppliers to service providers (such as shipbuilders, highway and bridge agencies, construction companies, and fuel producing companies), (2) service providers (such as railroads, liner operators, and individual auto drivers), and (3) service users (such as manufacturers, farmers, and others) who incorporate transportation into their recipes for work, recreation, and other things. Depending their place in the transportation system, actors hold differing and limiting views of innovation processes and their outcomes. Consequently, potentials for dysfunction abounds.

Prior to discussing innovations, I present a general model of technology development. The constraints on technology development imposed by the incremental and historic path-dependence behaviors of systems are identified.

## 1. Introduction

Technological improvements over the centuries have yielded cheaper, faster, and better (less polluting, quieter, safer, more reliable) transportation services. Stories about this glorious history are usually in the language of vehicles, facilities, and propulsion. Wheeled wagons were in use at least 5000 years ago, and about 2000 years ago, swiveling front axles to aid steering were developed. Roman roads helped tie the Roman Empire together, as roads did for early empires in China and the Americas. Carts or sledges served where relatively good roads were not available. For millenia, most folks walked along trails, and horses, camels, and mules carried trading goods. Around 1800, steam was harnessed for propulsion and superseded sails and animals. Steam has been followed by gasoline, diesel, and turbine engines. Fuel cells are in development as of the turn of the twenty-first century.

Recalling these changes, it is fair to conclude that technology has improved rapidly in recent centuries. As late as 1800, the very best road wagon and ocean sailing services made it possible for mail, travelers, and goods to travle 150 km in 24 hours. At the turn of the twenty-first century, most of the world has far better services. Although some places are better served than others, and affordability and service quality are often at question, improved services are pretty much universally available.

It is too bad that the emphasis is on vehicles, facilities, and propulsion, for there is much more to transportation technology enhancement. The improvement of services matters, and stress should be on the processes that have induced and steered technological advances, increased the variety of services, and enabled transportation to serve ever more varied purposes. Networks have adapted to varied environments and demands and have often enabled activities to shift to places and environments for which they are best suited. In tandem with communication between people, activities, and places, improved transportation technology has increased trade in goods, ideas, and understandings, as well as daily, seasonal, and longer term movement of workers, students, and tourists. In these ways, interactivity capabilities enabled the growth of the middle classes and helped change the balance of economic and political power.

## 1.1. Transportation Developments

Technological advances have played a role in hundreds of years of successes (and failures). Looking back, waves of transportation development pushed older modes aside and supported sweeping social and economic changes. In each era, a set of technologies, services, or modes occupies the turf, so to speak. In the more developed nations of the late twentieth century, there are well established rail, air, short sea, ferry, auto, and other services. Perceptions, institutions, and activities tied to these services are also well established and entrenched.

As less developed economies mature, services are expanded either in response to market pull or as a result of investments intended to induce development. But although this enhances modes in many ways, their technologies and services are rooted in the conditions that existed at the time they emerged and therefore they may have attributes incompatible with the developed economy.

There are always concerns about sustainability and the consequences of continued growth along the existing path. These concerns focus on transportation's impacts on the use and management of resources. A second question, mostly out-of-mind, addresses the development and implementation of transportation innovations and improvements that help society to create and choose equitable and life improving development paths.

The challenge of transportation technology is to find efficient and sustainable development paths that also open options. Increasing efficiency by itself will not create the new environments that enable innovation. These environments may be as necessary in the future as they have been in the past to support the evolution of a more workable and equitable future for all sectors of society.

## 1.2. Plan for this Discussion

In the following discussion I recognize the linkages that tie transportation infrastructure and services to most aspects of modern life, as well as the roles transportation plays in advancing development. I begin by providing a general scheme or model describing how improvements in transportation technology and services increase innovation options for service users. I also introduce the diffusion of innovations.

Next, I place transportation improvement processes within the structure of services and note innovation recipes and their consequences and the roles of service providers, users, and others.

Recognizing transportation's main structural divisions, I then review how actors in service provider, user, and supplier-to-service-provider roles engage in innovation and technology development. It's a fragmented landscape, and I provide partial or myopic models of how actors perceive their diverse roles and the consequences of their actions.

I seek to orient the reader to how technology improvements create opportunities for development, and to the perceptions and activities of the many actors involved in improvements. The discussion has an ethnographic flavor because it outlines the structure

of activities and introduces the views and behaviors of actors.

The bibliography supports the discussion. It includes works on innovation and technology development processes within the modern modes, and for transportation in general.

## 2. Transportation Technology and Innovation

Innovation and technology development are everyday events in transportation as individuals work out how and where to travel and firms and other organizations arrange passenger travel and freight movement. Suppliers seek better materials and fuels, traffic engineers investigate improved methods for timing traffic lights, and warehouse managers balance inventory versus out-of-stock and shipment costs. Technologists search for stronger yet lighter vehicles and safety experts test new and existing technologies. These everyday activities lead to a variety of perceptions of processes, the relations among them, and their relative importance.

There are big events as well as everyday events. About one half of the US National Academy of Engineers list of the 20 greatest engineering achievements of the twentieth century were directly related to transportation or interactivity (Table 1). Just about all of the achievements involved transportation in some fashion. The mechanization of agriculture involved transportation technology improvements that served as building blocks for machinery manufacture, marketing, and the shipment of farm products. Achievements like airplanes and highways were inputs for services that vastly expanded consumption and production options.

| Rank | Achievement |
|---|---|
| 1 | Electrification |
| 2 | Automobile |
| 3 | Airplane |
| 4 | Water Supply and Distribution |
| 5 | Electronics |
| 6 | Radio and Television |
| 7 | Agricultural Mechanization |
| 8 | Computers |
| 9 | Telephone |
| 10 | Air Conditioning and Refrigeration |
| 11 | Highways |
| 12 | Spacecraft |
| 13 | Internet |
| 14 | Imaging |
| 15 | Household Appliances |
| 16 | Health Technologies |
| 17 | Petroleum and Petrochemicals |
| 18 | Laser and Fiber Optics |
| 19 | Nuclear Technologies |

| | |
|---|---|
| 20 | High-Performance Materials |

Table 1. Great engineering achievements of the twentieth century
From <www.greatachievements.org>.

## 2.1. Technology Development Process

Technology and its root innovation is worthless without a market. This helps us to understand and value innovations in the context of history as a whole. How do technological improvements enable and enhance activities that are worth doing anyway? Hype doesn't count, as G. Mensch pointed out when he called things of much hype and little consequence pseudo-technologies.

Next, recall lessons from the sweep of history that provide patterns for interpreting current activities.

The main pattern is this: When improved transportation technologies enhance services, people and things move more easily and communication increases. Consumers have increased information and choices among goods and services, as well as opportunities for socialization and recreation. Producers may substitute higher grade resources for lower grade ones and larger and more varied markets may become available. The expanded geographic scope opens opportunities for changes in spatial organization and economies of scale. Opportunities for specialization increase as new markets and production tools and materials segment consumption and production. Adam Smith made these points in the chapter on the division of labor in his 1776 work, *The Wealth of Nations*.

As production, consumption, organizational, and raw material options increase, new technologies appear which serve many purposes. These companion innovations result from innovations enabled by improved transportation. Also, innovations already available but not widely adopted diffuse rapidly with better transportation and communication, and new resources and markets.

This process repeats as road and wagon services, canal and river improvements, rail services, and auto and air services interact with communications and other improvements to yield sweeping or revolutionary developments (Figure 1). In this way, transportation systems relate to political, capitalist, governance, and cultural systems, to the spread of plants and animals and also to the broad sweep of history and geography.

There are many examples of developments of this sort. A sequence of maps of a rural area will show how the availability of the automobile enabled the consolidation of small schools into larger ones for education that is more efficient and new socialization activities. (That was progress for the times. Today's large school districts with impersonal bureaucracies are another matter.) Commerce that uses the increased information and variety of the Internet follows the pattern of interurban railroad and auto service enabling growth of larger shopping towns and their increased choices compared to the country store.

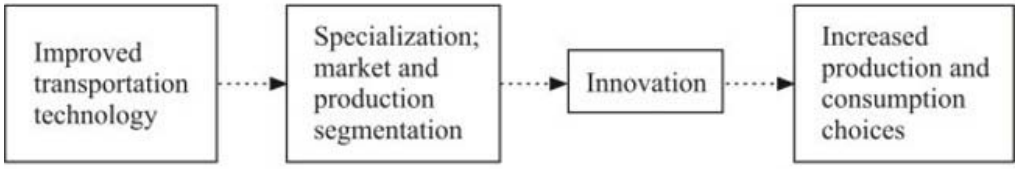


Figure 1. A general model of innovation and technology development in transportation Improved services enable innovations and increase consumption and production choices.

The process is a sequence of steps. In Step 1 innovation yields cheaper, faster, better transportation services. These improved services enhance existing activities. In Step 2, improved services enhance existing activities, and both spread and create new activities.

Step 1 results in more efficient production and consumption, and that is certainly worthwhile. Yet the social and economic advances of Step 2, associated with this technological change, are much more important because they enable more consumer and production choices, and productivity gains. These are major improvements in the human condition.

Perhaps the great French engineer-economist Jules DuPuit partially recognized this type of advance in 1844 when he commented, "The ultimate aim of a means of communication must be to reduce not the costs of transport, but the costs of production."

### 2.2. Discussion of the Process

This two step process enables interactivity-based innovations in economic and social arenas. Recalling examples helps to understand the process. Consider the emergence of truck transportation services. Services emerged about 1910 when trucks substituted for animal-drawn wagons. This enhanced existing services such as coal delivery within cities and household goods movements among cities.

New activities emerged a decade or so later as truck freight services combined with factory and warehouse technologies. Activity sites shifted away from downtown railroad yards. Automobiles, streetcars, and telephone services supported these changes. New industries, consumption patterns, and lifestyles emerged as truck, auto, and air services enabled developments in health, education, and recreation.

The diffusion of railroad services illustrates how cheaper, faster, and better transportation enables advances. Farmers in the Great Lake states improved and spread the use of the mechanical reaper, an existing technology in limited use. Grain futures markets and large scale grain storage then appeared in this region, combining railroad service and the telegraph as building blocks. In England, the average distance between the home addresses of newlyweds in the mid-1800s increased from 10 to 20 km, suggesting that rail service increased marriage options by about a factor of four.

In subsequent discussion, I will refer to the two-step process will be referred to as the full or general model, as opposed to more partial or myopic models of processes. The general process extends to the full scope of interactivity capabilities that provide for such things

as increased specialization and market and production segmentation and the diffusion of ideas and knowledge. Allied phenomena include the accumulation of capital and knowledge.

### 2.3. Temporal and Spatial Realizations

New modes or systems emerge with workable technological formats. These modes and services claim markets. Railroads emerged in the 1830s, modern highway-based services in the 1900s, air services in the 1930s, and container liner services in the 1950s. These incorporate precursor technologies, and improve as they diffuse to varied environments and markets. These features of development, growth, and diffusion make for rather fuzzy dating of beginnings and market saturation. Even so, it is fair to generalize that network building and market capture takes about 60 years.

S-shaped curves that chart diffusion over time effectively represent market penetration and technology diffusion. A chart of railroad trackage expansion in the US, for example, shows miles of track increasing rapidly by the 1860s with maximum mileage achieved by about 1920. Automobile use took off in the 1910s, and by the mid-1920s about two families in three in the US owned an automobile. By the late twentieth century, the market is well saturated and there are at least as many automobiles as eligible drivers. Diffusion's S-shape curve highlights technology's self-limiting characteristic, which forecasters and critics often ignore. Saturated markets and technology that is honed to diminishing returns limit both growth and development.

S-shaped curves summarize the temporal and spatial realization of systems driven by the two step process. Structural features of transportation systems, institutional interactions, and the perceptions, roles, and behaviors of system actors also drive and frame the process. Subsequent sections cover these topics.

### 2.4. Winners and Losers

The diffusion and adoption of technologies for cheaper, faster, and better service disrupts old arrangements. New raw material procurements and market areas loosen local monopolies. Free market players and more protectionist, feudal perspectives conflict in every era. Beckless Willson remarked in the late 1600s that country towns condemned road and coach improvements because they expanded London's influence and injured local trade. By the mid-1800s, George P. Marsh recognized that the spread of development was changing the face of nature.

Improving existing activities uses human and natural resources more effectively and increases productivity. Labor requirements may decrease, or capital and labor may become obsolete. For example, there has been concern that automation would displace workers of all sorts. However, new technology may increase opportunities for individuals and organizations. More technological variety creates increased demand for services, as well as more opportunities.

New forms of production and consumption give an advantage to those able to participate and make use of them. In part, the advantaged folks are lucky, but age, education, and

other factors play a role in who wins and who loses. Those left aside lose compared to those who participate.

Joseph Schumpeter used the term creative destruction to describe the chaotic disruptive changes that occur when the status quo is upset. The term “Luddite” derives from the followers of textile factory worker "General" Ludd, who saw machines as symbols of the displacement occasioned by the Industrial Revolution. During the twentieth century, social programs were created to smooth these disruptions.

Finally, not everyone finds the proliferation of choices and varieties of opportunities socially desirably. One hears laments that transportation and communication improvements create mass culture, and that the texture of society has lost variety. Critics target especially automobiles and air transportation. At the same time, critics lament the divisiveness of mobility along with advertising, communications, publishing, and educational curricula. Folk are turning away from commonly held views and values, and critics say this harms social welfare.

The impacts of cheaper, faster, and better transportation services are complex. It is too bad that resistance to change often dominates debates and increases in variety are not imagined or considered. Current impressions shape debates, and lessons from the broad sweep of history are ignored.

## 3. Structure, Behavior, and Performance

Transportation technologies are commonplace at the turn of the twenty-first century. We often take their relative importance, their development, and the way they provide services and interconnect other activities for granted. This section introduces structural, behavioral, and performance aspects of systems to identify these patterns.

### 3.1. Supplier, Service Provider, and User Technologies

Many of society's production activities sustain transportation. Society's production and consumption activities energize transportation service provision. Looking beyond movements within networks to the inputs and outputs sets technological advances within the context of (1) input sources, (2) transport service activities, and (3) transport users. That is, input technologies, service provider technologies, and user technologies are linked.

Equipment manufacturers, designers and construction contractors, financial and insurance organizations, driver- or pilot-training schools, and others provide inputs. The modes provide services. User system activities involve just about all members of society because transportation is a building block for recreational and other consumption activities, as well as for production systems from resource extraction to management consulting. Governments, schools, and medical services shape and are shaped by transportation services.

Input, service provider, and user innovation and technology development venues provide a structural template for this discussion.

### 3.2. Innovator Roles

Actors perspectives depend on their role at the moment. The American car and truck manufacturer (input supplier) Walter P. Chrysler stressed speed in a 1927 interview, "By speed I don't mean breakneck travel for the sake of thrill, but quickness in getting somewhere to do something useful quickly." When driving at speed, Chrysler was a service provider (providing services for himself) and when “doing something useful” he was a service user. When constructing a loading dock the firm is supplying a facility, which is an input to service. It is a service provider when managing its fleet of trucks and a service user when running the business that combines transportation services with other activities.

Movement among role is an everyday occurrence as is innovation. Every kind of behavior imaginable is present, ranging from self-serving and monopolistic to altruistic. Of course most actors would not think of themselves as innovators even though they are innovating; they may think of an innovation as something produced by white-coated engineers in laboratories instead of a new way to approach an everyday problem. They are just doing what they can do within the constraints of system structure, their own perceptions of processes, and their social norms. Also, they are often innovating through imitation and adaptation of existing technologies.

Innovative behavior falls into enhancing and enabling categories.

#### 3.2.1. Enhancing Performance

The processes that link technological improvements to cheaper, faster, and better services are common to many venues. We usually think of processes within a fixed or static framework, and because most actors behave as if this is the case, change is slow. Convention and norms limit innovators, managers, analysts, users, and others. Individuals and organizations monitor evolving technological tools and apply them for marginal advantages. By improving product quality, they *enhance* the performance of existing activities and things.

Advances are often incremental and rather disjoint. Energy suppliers developed better fuels, others improved protective coatings, and aviation agencies improved airway and airport traffic controls. Although advances have an incremental and disjoint nature, competition energizes technology development and efficiency motivates the adoption of improved technologies. Also, industry and governments impose standards and social habits and norms accelerate or constrain technology development and adoption.

Society often seeks technological solutions to important issues or problems. At the turn of the twenty-first century, for example, technologies are sought to improve safety at railroad crossings and further decrease pollutant emissions from automobiles. Technology has provided many enhancements for parsimony and sustainability. Over the second half of the twentieth century, for example, air travel energy use per seat mile decreased about 70%. Possible further reductions extend to combustion products such as soot and oxides of nitrogen.

Enhancements are welcome, but the activities that produce them have worrisome features. Returns from innovation may diminish to the point where more effort just isn't worthwhile. Improvements may have both positive and negative consequences. For instance, lighter automobiles use less fuel but can have increased collision injuries and fatalities. Also, the increased number of required lifeboats following the Titanic disaster decreased the stability of some small ships. The framework for innovation and deployment processes may distort the search for technologies and their implementation, as well as consideration of impacts.

### 3.2.2. Enabling Technologies

Transportation's connection and interaction functions create another improvement opportunity . When technological improvements extend services to new users or increase the variety of services offered they open opportunities for new modes of production and consumption, as well as for socialization and cultural activities. Users may take up opportunities not previously available or innovate new activities. In this way, transportation serves an *enabling* function, creating qualitative changes in everyday life and society.

Developments in communications, financing, and management support and are supported by transportation improvements. Transportation technologies played roles in the great waves of progress associated with the printing press, sailing ships, canals, banking, emergence of the merchant classes, railroads, mail and telegraph services, industrialization, urbanization, the trolley, automobile, truck, and telephone. At the end of the twentieth century, the interactivity produced by small batch and parcel shipments, computers, other communication devices, and automobile, truck, and air transportation are enabling another wave of progress. These are very reliable, user friendly services.

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**Biographical Sketch**

**William l. Garrison** is Professor Emeritus of Civil and Environmental Engineering and Emeritus Research Engineer in the Institute of Transportation Studies, University of California, Berkeley, His professional concerns and current work focus in the main on technological change in large systems, especially transportation systems.

Born in 1924, Garrison's first instruction in conservation and resource renewal was in 1936. Later he received his bachelor's and master's degrees from Peabody College in Nashville, Tennessee, and in 1950 he received his PhD in geography from Northwestern University in Evanston, Illinois. Garrison served as a meteorologist during World War II. In addition to working in geography and civil engineering, he has been a truck driver, surveyor, and mechanic. He is a seven times father and fourteen times grandfather.

Somewhat of a job hopper, Garrison has held positions at the University of Washington, Northwestern University, University of Pennsylvania, University of Illinois, and University of Pittsburgh, as well as the University of California. During the 1950s he was a Lecturer in the Brookings Institution's Urban Policy Program. Garrison's "Lessons From the Design of a Life," (pp. 99–123 in Geographical Voices, Syracuse University Press, 2002, edited by Peter Gould and Forrest R. Pitts) describes these adventures.

In the 1950s and 1960s Garrison served on the Research Advisory Committee and the Advisory Committee on the Highway Cost Allocation Study of the Bureau of Public Roads. Later he served on the National Research Council Research Advisory Committee to the US Department of Transportation; the Independent Study Board of the US Department of Commerce; the Advisory Committee on Small Area Data of the US Bureau of the Census; the Committee on Research of the Economic Development Agency of the US Department of Commerce; the Committee on Economics of the National Science Foundation; the Study Committee on the Social Sciences of the National Science Board; and the Commission on Sociotechnical Systems of the National Research Council. He has also served as a consultant to government, nonprofit, and business organizations; the National Transportation Policy Study Commission; and as Chairman of the Transportation Research Board. He has served on the editorial boards of several journals. These and similar activities seem not to have done harm and may have been useful.

Some of Garrison's recent works include: "Innovation and Transportation's Technologies," published in 2000 in volume 34 of the Journal of Advanced Transportation (pp. 31–63); Tomorrow's Transportation: Changing Cities, Economies, and Lives, (with Jerry D. Ward; Norwood, Massachusetts: Artech House, 2000, 316 pp.); and "Relations Between Transportation and Production," with Soulerette R.R. (Transportation Research Record 1262, 1990). Soon to be published are contributions to the UNESCO Encyclopedia of Life Support Systems. Some years ago, Garrison organized the first US conference on intelligent vehicle–highway systems (IVHS) yielding the report Technology Options for Highway Transportation Operations, published by the University of California Institute for Transportation Studies and California Department of Transportation (UCB-ITS-P-87-1, 1987).