

# UC Berkeley

## Earlier Faculty Research

**Title**

Technological Changes and Transportation Development

**Permalink**

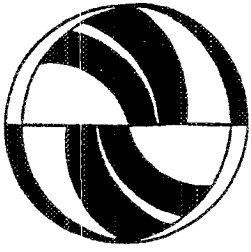
<https://escholarship.org/uc/item/0md4p4s5>

**Author**

Garrison, William L.

**Publication Date**

2001



**Technological Changes and Transportation  
Development**

William L. Garrison

Reprint  
UCTC No 495

The University of California  
Transportation Center  
University of California  
Berkeley, CA 94720

**The University of California  
Transportation Center**

The University of California Transportation Center (UCTC) is one of ten regional units mandated by Congress and established in Fall 1988 to support research, education, and training in surface transportation. The UC Center serves federal Region IX and is supported by matching grants from the U.S. Department of Transportation, the California Department of Transportation (Caltrans), and the University.

Based on the Berkeley Campus, UCTC draws upon existing capabilities and resources of the Institutes of Transportation Studies at Berkeley, Davis, Irvine, and Los Angeles; the Institute of Urban and Regional Development at Berkeley, and several academic departments at the Berkeley, Davis, Irvine, and Los Angeles campuses. Faculty and students on other University of California campuses may participate in

Center activities. Researchers at other universities within the region also have opportunities to collaborate with UC faculty on selected studies.

UCTC's educational and research programs are focused on strategic planning for improving metropolitan accessibility, with emphasis on the special conditions in Region IX. Particular attention is directed to strategies for using transportation as an instrument of economic development, while also accommodating to the region's persistent expansion and while maintaining and enhancing the quality of life there.

The Center distributes reports on its research in working papers, monographs, and in reprints of published articles. It also publishes *Access*, a magazine presenting summaries of selected studies. For a list of publications in print, write to the address below.



University of California  
Transportation Center

108 Naval Architecture Building  
Berkeley, California 94720  
Tel: 510/643-7378  
FAX 510/643-5456

**DISCLAIMER**

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated under the sponsorship of the Department of Transportation, University Transportation Centers Program, in the interest of information exchange. The U.S. Government assumes no liability for the contents or use thereof.

The contents of this report reflect the views of the author who is responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the U.S. Department of Transportation. This report does not constitute a standard, specification, or regulation.

# **Technological Changes and Transportation Development**

William L. Garrison

Department of Civil and Environmental Engineering  
University of California  
Berkeley, CA 94720

Reprinted from  
*Encyclopedia of Life Support Systems*  
A UNESCO Publication (September 2000)

UCTC No 495

The University of California Transportation Center  
University of California at Berkeley

## 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 5,000 years ago, and about 2,000 years ago swiveling front axles aiding steering were developed. Roman roads helped tie the empire together, as roads did for empires in China and the Americas. Carts or sledges served where relatively good roads were not available. For years most folks walked along trails and horses, camels, and mules carried trading goods. About 200 years ago steam was harnessed for propulsion superseding sails and animals, and steam has been followed by otto cycle, diesel, and turbine engines. Fuel cells may arrive tomorrow.

Recalling these changes, it is fair to conclude that technology has come a long ways and improved rapidly in recent centuries. Just 200 years ago the very best road wagon and ocean sailing services let the mail, travelers, and goods go 150 km in 24 hours. Nowadays, 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. It's the improvement of services that matters, and stress should be on the processes that have induced and steered technological advances, increased the variety of services, and enabled transportation's serving ever more varied purposes. Networks have adapted to varied environments and demands and they often have enabled the shift of activities to those places and environments best suited for them. Working with communications and other capabilities providing for the interactivity of people, activities, and places, improved transportation technology has enabled increased trade in goods, ideas, and understandings, as well as the daily, seasonal, and long term movements of workers, students, tourists, and others. Working in these ways, interactivity capabilities enabled the growth of the middle classes and changes in balances of economic and political power.

### 1.1 Today's Challenges

There have been hundreds of years of successes (and failures) enabled by technological advances. Looking back, waves of transportation development pushed the older modes aside and enabled sweeping social and economic changes. Nowadays, a set of technologies, services, or modes occupies the turf, so to speak. In the more developed nations, there are well established rail, air, short sea, ferry, auto, and other services. Also well established are perceptions, institutions, and activities tied to the services provided by the modes.

As have-not economies seek improvements, services are expanded either in response to market pull or as a result of investments intended to induce development. But although the modes have been enhanced in many ways, the technologies they use and the services they provide are rooted in conditions at the time they emerged and they may have attributes inappropriate to modern times and new places.

Today as yesterday there are concerns about sustainability--the untenable consequences if growth continues along its present path. A second challenge seems mostly out-of-mind. It is that of enabling the innovations that society will need as it elects equitable and life improving development paths. To be sought are paths that have parsimonious, sustainable aspects and also option-opening aspects. Doing old things in more parsimonious ways is not enough for enhanced innovation-enabling environments may be as necessary tomorrow as they have been in the past to the evolution of more workable-equitable futures for all sectors of society.

### **1.2 Plan For This Discussion**

The discussion to follow recognizes the linkages tying transportation infrastructure and services to most aspects of modern life, as well as the roles transportation plays in advancing development. It begins by providing a general scheme or model describing how improvements in transportation technology and services increase options for innovation by the users of services. Aspects of the diffusion of innovations are introduced.

Next, the discussion places transportation improvement processes within the structure of the provision and use of services. Innovation recipes and their consequences are noted and the roles of service providers, users, and others are introduced.

Recognizing transportation's main structural divisions, the remainder of the discussion reviews how actors in user, service provider, and supplier-to-service-providers roles engage in innovation and technology development. It's a fragmented landscape, and partial or myopic models are provided to indicate how actors perceive their diverse roles and the consequences of their actions.

The discussion seeks to orient the reader to the ways technology improvements create

opportunities for development, as well as to introduce the perceptions and activities of the many actors involved in improvements.

The bibliography is scoped to the span of the discussion. It provides access to information on innovation and technology development processes within the modern modes, as well as for transportation generally.

## 2. Innovation and Transportation's Technologies

Innovation and technology development is an everyday event 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 stock-out and shipment costs. Technologists search for stronger yet lighter vehicles and safety experts test and test. Such everyday activities lead to highly varied perceptions of processes, the relations among them, and their relative importance.

Table 1 Greatest Engineering Achievements of the 20th Century<sup>a</sup>

- |                                  |                            |
|----------------------------------|----------------------------|
| 1. Electrification               | 11. Highways               |
| 2. Automobile                    | 12. Spacecraft             |
| 3. Airplane                      | 13. Internet               |
| 4. Water Supply and Distribution | 14. Imaging                |
| 5. Electronics                   | 15. Household Appliances   |
| 6. Radio and Television          | 16. Health Technologies    |
| 7. Agricultural Mechanization    | 17. Petroleum and          |
| 8. Computers                     | Petrochemicals             |
| 9. Telephone                     | 18. Laser and Fiber Optics |
| 10. Air Conditioning and         | 19. Nuclear Technologies   |
| Refrigeration                    | 20. High Performance       |
|                                  | Materials                  |

<sup>a</sup>[www.greatachievements.org](http://www.greatachievements.org)

There are big events as well as everyday events. Referring to the US National Academy



of Engineers list of the 20 greatest engineering achievements of the 20th Century, it appears that about one half of these were transportation and interactivity related (Table 1) Realizations of just about all of the achievements involved transportation in some fashion In cases, such as the mechanization of agriculture, transportation technology improvements served as building blocks enabling machinery manufacturing and marketing and the shipment of farm products. Achievements, such as airplanes and highways, were inputs for the provision of services that vastly expanded options for consumption and production.

### 2.1. The Technology Development Process

To sort out how everyday innovative endeavors and larger events are related and to evaluate the relative importance of activities, recall that a technology is a zero unless there is a market, and the same is true for the innovation that created it. The question is that of how technological improvements enable and enhance doing things that are worth doing Hype doesn't count, a point made very well by G. Mensch when he termed things of much hype and little consequence pseudotechnologies.

Next, recall lessons from the sweep of history. Those lessons provide patterns for interpreting today's activities.

The main pattern is this: When improved transportation technologies enhance services, people and things move more easily and communications are increased. 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. Expanded geographic scope opens opportunities for changes in spatial organization and achievement of economies of scale.

Opportunities for specialization are increased as consumption and production are segmented by markets and the production tools and materials that become available. Adam Smith made these points over 200 years ago in his chapter on the division of labor

Production and consumption options increase and these plus organizational and raw material options enable innovation and the creation of new technologies serving many purposes. These may be thought of as companion innovations, they are the result of innovative activity enabled by improved transportation.

Also, innovations already available but not widely adopted may be rapidly diffused as transportation and communications are improved, new resources made available, and markets increased

That, in a nutshell, is the process that played over and over again as road and wagon services, canal and river improvements, rail services, and auto and air services interacted with communications improvements and advances in other sectors to yield sweeping or revolutionary developments (Figure 1). The process related transportation systems to the larger world of political, capital accumulation, governance, and cultural systems and to such things as the diffusion of plants and animals and much of the broad sweep of history and geography.

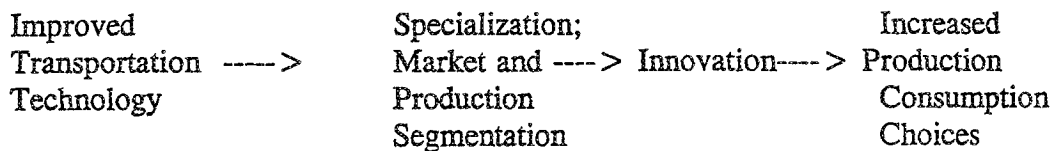


Figure 1. A General Model of Innovation and Technology Development in Transportation. Improved services enable innovations and increase consumption and production choices.

Example after example of developments of this sort are seen just by looking back and

looking around. A sequence of maps of a rural area will show how automobilization enabled the consolidation of small schools into larger ones. Reading, writing, and arithmetic could be taught more efficiently and new educational and socialization activities became possible. (That was progress for the times. Today's large districts with impersonal bureaucracies are another matter ) Today's internet-based commerce and its offering more information and choices adheres to the earlier experience when interurban railroad and auto service induced growth of larger shopping towns and the increased choices they offered compared to those available at the country store.

The process may be described as a sequence of steps. In Step 1 innovation yields cheaper, faster, better transportation services. These improved services enhance the ways old things are done. In the next step, Step 2, improved services may open opportunities to do old things in new ways, to adopt innovations already available, and to innovate new activities.

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

Perhaps the great French engineer-economist Jules DuPuit was partially recognizing the scope of advances when in commenting on transportation improvements in 1844 he remarked, "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**

It's the two step process that enables interactivity-based innovations in economic and

social arenas, and understanding the process is aided by recalling examples of the process at work. Consider, for example, the emergence of truck transportation services. Services emerged about 1910 when trucks operated by hauling firms began to substitute for animal drawn wagons. Existing services were enhanced, and coal delivery in cities and household goods movements between cities were early examples of doing old things better.

New activities began to emerge a decade or so later as innovative individuals and organizations began to combine truck freight services with factory and warehouse technologies, and one consequence was the shift of activity sites away from downtown railroad yards. Automobile and streetcar services were supportive of changes, as was the development of telephone services. Broadly, new industries, patterns of consumption, and lifestyles emerged as truck, auto, and air services enabled a variety of developments in health, education, socialization and recreation, and other sectors.

The diffusion of railroad services provides more illustrations of how cheaper, faster, better transportation services have enabled advances. The mechanical reaper, a technology already developed but in limited use, was improved and became widely used by farmers in the US Lake States, and that region hosted the emergence of grain futures markets and large scale grain storage, combinations of things using 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 a rail service enabled increase of marriage options by about a factor of four.

In subsequent discussion 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/Spatial Realizations Of The Process

New modes or systems emerged when workable technological formats were found and they and the services they provided claimed their markets. Railroads emerged in the 1830s, modern highway-based services in the 1900s, air services in the 1930s, container liner services in the 1950s, and beginnings may be marked for other services. The systems incorporated aspects of precursor technological formats, and they were improved as they were diffused in varied environments and as they interfaced with and shaped markets. These features of development, growth, and diffusion make for rather fuzzy dating of beginnings and market saturation. Even so, it is fair to say that market capture takes about 60 years.

Market penetration and technology diffusion are represented quite well by S-shaped curves, say, by charting a measure of diffusion versus time. A chart of railroad trackage expansion in the US, for example, would show the miles of track increasing rapidly by the 1860s with the maximum mileage achieved by about 1920. Automobile use took off in the 1910s, by the middle 1920s about two families in three in the US owned an automobile. Nowadays the market is well saturated--there are about as many automobiles as there are folks eligible to drive. The adherence of diffusion to S-shaped curves highlights the self limiting characteristics of technologies, a feature often ignored by forecasters and critics. Both growth and development are limited as markets are saturated and technologies are honed to diminishing returns.

S-shaped curves give summary views of the temporal/spatial realization of systems whose

development is driven by the two step process. The pattern is also driven and framed by the structural features of transportation systems, institutional interactions, and the perceptions, roles, and behaviors of system actors, as well as myriad other things. These subjects will be taken up in subsequent sections of this discussion

#### 2.4 Winners and Losers

The diffusion/adoption of technologies providing cheaper, faster, better services disrupts old arrangements. New arrangements of raw material procurement and market areas may loosen the strength of local monopolies. Here the conflict is between those seeking the play of free markets and mercantilism and those desiring more protectionist, feudal arrangements. Such conflicts are mentioned today as yesterday. Conflicts are not new. Commenting on the improved roads and coaches of the late 1600s, Beckless Willson remarked that improvements were condemned by the country towns because they expanded the influence of London and injured their trade. By the mid 1800s, George P. Marsh was recognizing how the spread of development was changing the face of nature.

Doing old things better uses human and natural resources more effectively and increases productivity. A consequence may be reduced labor requirements, as well as obsolete capital and labor. Only a few decades ago, for example, there was concern that automation would displace workers of all sorts. However, doing new things may increase opportunities for individuals and organizations. Variety increases mean more needs to be done, as well as more opportunities to do things.

New forms of production and consumption advantage those able to participate and make use of them. In part, the advantaged folks are at the right time and place, so to speak, but there

are age, education, preference, and other factors involved 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. Indeed, the term Luddites derived from the followers of textile factory worker "General" Ludd, who saw machines as symbols of the displacements occasioned by the industrial revolution. Nowadays there are a variety of social programs geared to smoothing the transitions occasioned by disruptions.

Finally, not everyone finds the proliferation of choices and varieties of opportunities socially desirable. One hears laments that transportation improvements have led to mass culture, the texture of society no longer has the variety it once had. That comment is addressed especially to the effects of automobilization and air transportation. At the same time, critics lament how today's mobility along with modern advertising, communications, publishing, and educational curricula are divisive. Folk are turning away from commonly held views and values, and critics say this does not bode well for social welfare.

The impacts of cheaper, faster, better transportation services are complex. It is too bad that costs often dominate debates and increases in variety and choices are neither imagined nor considered.

### **3. Technologies for Producing and Using Transportation**

Transportation's technologies are an everyday fact, they are there for all to see and use. Taken for granted, questions about their relative importance and lessons bearing on how they are developed, provide transportation services, and interconnect other activities are often out-of-sight and out-of-mind. To begin to tease-out patterns, consider the provision and use of

transportation services.

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

Movements of people and things on transportation networks are sustained by inputs from many of society's production activities and society's production and consumption activities energize service provision. So looking beyond movements on networks to inputs and outputs will set technological advances within the contexts of (1) those providing inputs to transport services, (2) the activities of transport service providers, and (3) what users of services do. That is, there are linked

Input Technologies  
Service Provider Technologies and  
User Technologies

Inputs are provided by equipment manufacturers, airport designers and construction contractors, equipment financing and insurance organizations, and driver- or pilot-training schools, as well as by many other of society's activities. The modes provide services. And just about everyone is involved in user system activities because transportation serves as a building block in recreational and other consumption activities, as well as in production systems ranging from resource extraction to management consulting. Governments, schools, and medical services shape and are shaped by the ways transportation services are used.

### 3.2 Roles of Innovators

Sorting out who plays in what venues can be fuzzy because just about all folks are in the action, in the play, so to speak. Their perspectives depend on where they are standing at the moment. The American car and truck manufacturer (input supplier) Walter P. Chrysler stressed speed in an interview in 1927 remarking, "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--doing things enabled by transportation services. When constructing a loading dock the firm is supplying an input, a facility. 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 things.

Participating roles are everyday things, and innovation is too as people and institutions strive for goals. 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 working out ways to do things; they may think of an innovation as something produced by white-coated engineers in laboratories. They are just doing what they can do within the constraints of system structure, perceptions of the ways things work, and social norms. Also, they are often innovating by imitating and adapting technologies created elsewhere.

Looking around and looking back at the sweep of history, innovative behavior sorts into enhancing and enabling categories.

### 3.2.1. Enhancing Performance

The processes linking technological improvements to cheaper, faster, and better services are similar to those working in many venues. Processes are usually thought of as taking place within a fixed or static framework, and because most actors behave as if this is the case, things are slow to change. Innovators, managers, analysts, users, and others are set-in-their-ways, so to speak. In this situation, individuals and organizations monitor evolving technological tools and apply them where there are marginal advantages to be had. They *enhance* the performance of

existing activities and things.

Advances are achieved in a step by step, incremental and rather disjoint fashion. Looking back, better fuels were developed by energy suppliers, protective coatings were improved by others, and aviation agencies have improved airway and on-airport traffic controls. Although constrained by this incremental/disjoint context, competition energizes technology development and efficiency motivates the adoption of improved technologies. Industry or government imposed standards and social habits and norms may accelerate or constrain technology development and adoption.

Issues and problems loom large. Problems are recognized and technology is asked to manage them, to "fix" them. Today, for example, technologies are sought to improve safety at railroad crossings and further decrease pollutant emissions from automobiles. There is also the call for enhancements that ensure parsimonious/sustainability attributes. Much has been achieved. Over the last 50 years, for example, the energy use per seat mile in air travel has decreased about 70%. Today's call is for further reductions; it extends to products of combustion such as soot and oxides of nitrogen.

Enhancements are welcome, but they are achieved by activities that have worrisome features. Returns from innovation may diminish to the point where more effort just isn't worthwhile. An improvement one place may have negative consequences elsewhere, as was the case when the fuel efficiency obtained by reducing the weight of automobiles contributed to increased injuries and fatalities from automobile accidents and when increasing the number of lifeboats following the Titanic disaster decreased the stability of some small ships. Also, the structure or framework for innovation and deployment processes may distort the search for

technologies and their implementation, as well as the ways the scopes of impacts are considered.

### 3.2.2. Enabling Technologies

The ways that transportation serves connecting or interactivity functions frame another role and style for technological improvements. 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 and socialization and cultural activities. Users may take up opportunities not previously available or they may innovate new activities. In this way, transportation serves an *enabling* function. It enables qualitative changes in the ways folks live and society functions.

Transportation enables by drawing on and triggering developments in communications, financing, and management, as well as improvements in other activity sectors. This was the way improved transportation technologies played roles in the great waves of progress associated with the printing press, sailing ships, canals, banking, and the emergence of the merchant classes; the railroads, mail and telegraph services, and industrialization; and urbanization and the trolley, automobile, truck, and telephone. Today, small batch and parcel shipments, computers and communications devices, and automobile, truck, and air transportation are enabling another wave of interactivity-enabled progress. These are high reliability, user friendly services.

### 3.3 The Combining Recipe

Innovation creates technologies, and technologies are innovated/created by combining. Combining is not a process limited to transportation for in all sectors innovators combine things and technologies are the result. For example, mechanical cooling emerged when heat pumps were combined with insulated boxes and personal computers combined chips, storage media, and

input/output devices.

Similar combining stories hold in the air and on the road, rails, or water--things are combined for useful purposes. To achieve transportation services, the trucking firm combines equipment and drivers, roads and routes, and controls that guide operating the business. Transport occurs when dispatchers assign trucks and send drivers on schedules and routes and do other things to produce services.

The combining of things to provide transportation services is an everyday occurrence as billions of travelers reason out and act to get from here to there and shipments are packaged and dispatched in this way or that

Those providing inputs to transportation services also combine things. The very successful Douglas Corporation Model 3 (DC-3) airframe of the 1930s and 40s combined all-metal construction, retractable wheels, and radial engines, radio navigation, and some other things. Those who improve railroad track combine ultrasonic measurement of fatigue cracks in rail with distance measurement techniques and automated measurement of track alignment in order to define needs for maintenance.

Innovative individuals combine transportation services with other things to take advantage of production and consumption options. That may seem a commonplace everyday thing, and it is. It involves variations on well known recipes and imitation of what one did yesterday and what others do. But even though seeming mundane and commonplace, this day-to-day innovation of uses is consequential because of the ways it affects so many lives. For the individual it is a large part of the design of life and payoffs are large. As individuals and organizational users create technologies they steer transportation development.

In spite of the everyday character of combining, it is often not considered in proposals for technology development, and that is too bad. When comparing the cost and time of intercity travel, for example, it might be imagined that a new technology: cheaper, faster train would displace automobile travel. But that assumption might be faulty if the opportunities to use an automobile at the destination were not considered. Here the question turns on opportunities to combine activities at multiple destinations.

### 3.3.1 Disjoint Incrementalism

Recipes for combining are easy to imagine but their implementation may be constrained. Constraints hold from the beginning of the supplier, service provider, and user sequence. The truck equipment supplier, for example, must design and produce trucks that fit road designs, weight and size limits, and existing patterns of purchase and use. The supplier is thus limited to incremental improvements that fit facilities, and operations. Extending the sequence forward, the trucking firm providing services is similarly constrained, and users' choices are too.

The result is disjoint incrementalism, a concept introduced when technology's enhancing role was discussed. Equipment suppliers must produce products matching roads and operations conditions. Roads are built and improved to match the equipment that will be operated, as well as operations protocols. Operations folks fit what they do within the constraints of the roads and equipment at hand. This same sort of constrained fitting and matching holds in all the modes and at supplier, service provider, and user decision levels. Indeed, disjoint incrementalism is characteristic of many infrastructure systems where the lethargic hand of capital invested in fixed facilities is felt.

### 3.3.2 Historic Path Dependence

A transportation system is marked by characteristics such as load carrying ability, energy use, and capital and labor costs. Such characteristics emerged after a period of trial and error--they predominated over variations. For this reason, each system is said to have a predominate technology even though there is some variation here and there in their technologies.

Once the predominant technology emerges, it tends to persevere, and this tendency is thought of as historic path dependence. History enters because technological formats reflect the conditions of the times and places of their emergence. Path dependence holds because systems develop along paths constrained by disjoint incremental decision making. Also, many aspects of transportation are subject to economies of scale. There are also economies of scope resulting from standardization enabling operations on networks. Economies of scale and scope mitigate against change.

The railroads are often used as an example of historic path dependence, and they illustrate how the development path depends on origins. A decade or so after George Stephenson and others began railroad building, steel wheel on T-shaped rail, cross ties, standard gauge, cars trained behind locomotives, and other technological attributes characterized railroads. Historic path dependence has yielded trains today that are very similar to those of yesterday. What's more, their track gauge is eighteenth century tramway in width, and the placement of cars in trains and other features also follow from conditions at the time of first railroad development or before.

It's true that there has been lots of change since the early days: larger cars and more cars on trains, improved train control systems, and more powerful diesel-electric and electric locomotives.

But even though there have been improvements, rail, highway, air, and other systems are yesterday's systems. Creatures of the circumstances of their beginning they have been preserved and polished. As the economic historian Paul David put it, "Historic path dependence forfeits the competitive race to the first off the starting line rather than the swiftest." Systems are ripe for technological improvements of a modernization sort but disjoint incremental decision making offers powerful resistance to thorough going change.

### 3.4 Linking Perceptions and Roles

Although fuzziness and varied perspectives go with the territory, so to speak, the input, service provider, and service user terms highlight the structure of transportation endeavors. In addition, they aid in explaining the diverse views of technology development and its consequences. That's because perceptions about the processes at work and their importance differ depending on where a person or organization is located within the structure. Highway suppliers see the transportation world in their way, container liner operators see another world, and e-commerce managers have their views of timely small package shipments.

In general, private sector suppliers are interested in market share and profits and public agencies seek process integrity and bureaucratic efficiency, and there is a similar split in the interests of private and public sector service providers. Suppliers and service providers are also alert to job creation and the impacts of investments on economic development. Users look for cheaper, faster, and better services and also prize "user friendly" characteristics that make it easy for folks to do what they want to do. Critics such as public policy wonks, energy specialists, economists, and architects, planners, and environmentalists have their views and they typically address limited aspects of the enterprise.

Diverse roles in transportation result in diverse perceptions about the processes at work and their consequences, as will be seen when examining the user, supplier, and service provider segments of transportation activities

#### 4. Innovations Within User Systems

Again, a technology is a zero without a market. As the economist Aaron Gellman remarked, "It is the sound of one hand clapping " So this discussion of how system structure, perceptions, and individual and organizational roles shape innovations and technologies begins with users of transportation services.

As already remarked, innovations by users are everyday occurrences, they are made in the course of day-to-day living. The individual at work, play, attending to family matters and doing other things combines transport services with other building blocks to accomplish purposes. Many aspects of work and play involve choosing from this here or that over there, one puts together combinations. Call this creating the technology of living and think of transportation technology as enabling the design of one's life, as already mentioned. That's really not a stretch at all; it just requires thinking about the obvious.

Combining transportation services with other things occurs when resort operators make decisions about investments and menus of offerings, retail and wholesale establishment managers make location, inventory, and delivery decisions, and the World Health Organization plans its programs. Such combining by individuals and organizations is everywhere.

Figure 2 is a representation of the ways individuals and organizations combine transportation for purposes useful to them. Sometimes, such as when decisions are made about the variety of rides to be offered at an amusement park, it is the accessibility to markets



provided by services that matters. In other cases, transportation has a more built-into-the-process character--examples are heliskiing or helifishing and the use of mobile robots in factories. However, such differences are more apparent than real. They follow from habits of thinking and language when considering where boundaries are drawn around activities--should we say access by helicopter to a fishing site and then fishing or is the package helifishing?

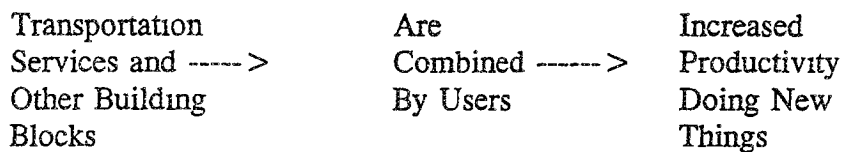


Figure 2 Users as Innovators. Users pick and choose among building blocks to improve what they have been doing or to do new things.

Less than two centuries ago transportation to final markets was built into farmers' tasks. In the Lake States in the US, for example, every Fall farmers drove animals and/or carried grain or whiskey in wagons seeking markets where they could be found. Nowadays modern transportation, communications, and marketing arrangements have enabled new ways to connect agriculture to markets.

#### 4.1 Increased Demand Pulls Technological Change

Although the process represented in Figure 2 is an everyday sort of thing, it seems mainly out-of-sight in the literature on the roles of users in innovation and technology development. Often, the consideration of user activities starts by identifying billions and trillions of trips by persons and ton miles of shipments. Then, there is emphasis on how expanded demand influences service providers (Figure 3). When travel behavior is considered, there is emphasis on such things as income and family size, service availability, and the modal choices made by users

Markets/users Want (Increased ----> or New) Services	Service Providers Improve Their-----> Technologies	Increase (Decrease) in Social Savings
--	--	---

Figure 3. How Increases in Uses Stimulates Technology Development and its Consequences

Figure 3 represents how increased activities of users are perceived and beg responses by those providing services. Increased uses may trigger crises from congestion, budget shortfalls, or pressures on natural resources. In the main, service providers cope by striving to increase what they have been doing. More-of-the-same means, say, larger aircraft and airport terminals, more cars on trains, or more lanes on freeways. There may be expansion of networks. These responses represent an improve-by-doing-more response to increased demand. This kind of response is expected in a world dominated by path dependant processes and where peer group and organizational values say do what you know how to do.

Increased demand may create opportunities for economy of scale capturing technologies such as automated terminals, expressways, and larger/specialized equipment. This was the case when larger and larger tank ships were deployed in response to increases in petroleum shipments. When increased demand results in congestion, congestion management technologies are developed and adopted. Increase in total demand may bring pressure on resources and ask that substitute technologies be developed, as has been the case for petroleum-based fuels.

The process is imagined to influence social savings. That is a with-or-without measure, and an illustration will convey the idea. Suppose a city has walking, bicycle, automobile, and bus-like services. Responding to increased demand, suppose that subway technology is developed and introduced. Social savings may be calculated by comparing the cost of serving the demand without the subway versus what it would cost with the subway. This is an everyday sort of

calculation, a generalization of benefit/cost and similar tools.

Nowadays, in the nations where market saturation characterizes the modes, social savings are often viewed as having no positive components, and increased pollution, congestion, and other negatives are stressed. Such negatives are projected as developing nations adopt the modern modes

#### **4.2 Further Consideration of User Innovations**

The perception represented by Figure 3 holds overwhelmingly in topical literatures, such as newspapers, and in policy and planning documents, academic journals, and government agency program descriptions. If considered, the loci of technology improvements induced by users are associated with service providers and the pay-offs from improvements are lower or higher transportation costs for users. Increases in fuel use and pollution are stressed.

But when looking back and examining the innovation and diffusion of transportation technologies, there is no denying the processes treated in the general model and restated in Figure 2. User innovations create new ways to do old things and enable doing new things. These enrich life, make for improved uses of resources, support the accumulation of capital, and do other good things

Why does looking around seem to give different answers from looking back? Perhaps the wisdom that society knows the costs of all things but the value of none applies. Perhaps the geologist's caution applies, "You won't find what you are not looking for." But those observations just turns the question to why no one is looking.

##### **4.2.1 Fast Variables, Slow Variables**

The fast variable, slow variable attributes of transportation systems may hide

relationships. For example, the number of aircraft and the capabilities of firms providing services have expanded in tandem with the growth of traffic, but airport capacity provision has lagged behind, as has the refinement of air traffic control technology. Coming along later also are the negative impacts from system operations. Perhaps when they were few the noise of trains and planes was not so bad. But with lots more service, impacts are quite apparent. Perhaps the ways that folks were advantaged when air services first became available are forgotten. So when one thinks of air transportation, the now familiar opportunities the service provides are overlooked and congested airports and noisy planes come to mind.

More generally, with yesterday's gains out-of-mind, transportation gets a bad press, so to speak. It is sometimes portrayed as an unnecessary or even pernicious activity that is a voracious user of steel, land, fuels, and other resources, a polluter of the lower atmosphere, and a destroyer of the upper atmosphere.

Perhaps working in an interrelated way is the lag between the outcomes of step one (doing old things better) and step two (innovations by users) as discussed for the general model and displayed in Figure 1. For many of today's modes, the major round of service improvements and perhaps the bursts of user innovations enabled by those improvements ran in yesterday's decades. The outcomes of changes are everyday experiences, but the roots of those changes are lost in the mists of yesterday. "Not much" is the answer to the question, "What have you done for me lately?"

But improvements are underway in some services. So perhaps rounds of service improvements and their consequences are taken as everyday events. An example may be today's changes in small shipment, exacting service quality market niches where improvements seem to

be taken as a matter of course. Such service began decades ago when service providers saw opportunities for services substituting for postal and local merchant delivery services. Service expanded rapidly as air transportation became available along with computer- and communications-based shipment controls and as user innovations in product assembly, merchandizing, and procurement then came along. To be seen today are just-in-time production and consumption, business-to-business internet markets, and lots of other action where transportation is a building block.

#### 4.2.2 The External Costs Paradigm

Perhaps the way economic externalities are defined and viewed partially explain why values are ignored. Externalities arise when the impacts of actions are not valued in markets and considered by consumers when taking actions. Transportation specialists often refer to congestion costs, the costs individual users imposes on other users. At least since work by Martin Beckmann in the 1950s, they have been aware that socially optimal flows on traffic networks require congestion cost pricing. When railroad use increased sharply in the 1800s, Charles Dickens pointed to the noise, smoke, and vibrations of train service and thus to the costs of environmental externalities. (With the disruptions of their construction forgotten, canals were by then "stately roads.") Much of the costs of accidents are external because they are not paid by users. Nowadays, emphasis is on the external costs of road transport, and environmental impact statements, mitigation actions, and tolls differentiated by time of day strive to identify and impose the cost of externalities on users. Regulations strive to reduce accident costs.

In 1971 the British economist E. J. Mishan dismissed the work of transportation economists as "largely bogus" because of not knowing enough about costs. That criticism would

certainly not hold today because nowadays there is a carefully reasoned and written literature that scopes external costs and the consequences of market failure (Absence the reflection of those costs in prices, there is excess consumption of highway transportation.)

The external cost paradigm is simple. It communicates easily, is accepted by economists, and offers a simple policy prescription. There is no one listening to the comment that it applies to a static system with fixed production and cost functions and does not consider either technological change or general equilibrium interrelations. That's too bad.

#### 4.2.3 More-Of-The-Same

Whatever the reasons for user's innovations and their values being out-of-mind, supplying more-of-the-same in response to users actions may foreclose opportunities and lead to dysfunctions. Recall that existing services have time and place characteristics. The railroads, for example, worked well in coal- and iron-rich England which was also blessed by the burgeoning mechanical arts. Subsequently, the technology was diffused, and in some places it fit circumstances well, but that wasn't the case everywhere. Railroads served well in the US where an observer in the late 1800s remarked that "Everywhere railroads went, science followed." That was saying that railroad service triggered the innovation and diffusion of technology.

Automobiles worked well in US cities, especially the new cities in the western part of the nation. There, streetcar services had exploded suburbs and agricultural, recreational, and other industries had decentralized employment. In those places automobile and truck service enabled new ways of living. But that result didn't hold everywhere.

Perhaps more-of-the-same responses to users' actions are inappropriate in new times or places? Perhaps limiting perception to more-of-the-same technologies can thwart even raising

the question of opening new development options by considering new services.

Actions that turn users' interests and ingenuity into more-of-the-same prescriptions for transportation service suppliers may be turning silk purses into sows' ears, so to speak.

### **5. Inputs to Service Providers**

Many if not most folks think of transportation's technologies as the products of those providing inputs to service providers--the auto and airframe manufacturers, shipbuilders, road and airport design and construction firms, and others who create and hone products to be used when transportation service is provided. Engineering and management organizations provide equipment, design, build, and maintain facilities, and develop and apply traffic control devices and control protocols. Financial organizations work with manufacturers and other input providers, and they provide insurance and other financial products to service providing organizations and individuals.

These are often large organizations employing scientists and engineers and professional managers. Labor unions are often involved, as are professional organizations such as the Society of Automotive Engineers. Government and industry association testing and standards setting organizations are also involved. The larger supplier organizations are monitored by the financial community and the press. The achievements and foibles of automobile and airframe manufacturers, labor unions, professional organizations, construction companies, and fuel producers are grist for debates of many kinds.

Some of these large, well organized activities steer clear of government involvement. but others find common interest in the promotion of government funded research and development (R&D) funding programs. Initiatives emerge from time to time, and one- to four-year research

and/or development projects are commonplace in government laboratories, private organizations, and university situations. They are the coin with which many scientists, technologists, and R&D organizations live. Recent initiatives have included vehicle safety, low pollution vehicles, more effective highway pavements, intelligent vehicles and highways, and improved control of aircraft moving on airports.

Although large organizations are in the public eye, a vast number of individuals and small organizations also provide inputs to service providers, and the fuel/service station operator is an example, as are automotive repair shops.

### **5.1 Improved Inputs Improve Services**

The work of civil, mechanical and other engineers and improved understandings of soil mechanics, lubrication, and strength of materials have been the raw materials from which improved products were crafted, and improvements continue in these traditional areas as new ones begin to contribute. Today, there is lots of interest in computers and control technologies, and work today is expected to yield technologies that will play large roles tomorrow. No doubt they will as intelligent cruise control, neural network concepts for traffic signal timing, navigation, control, and communication allowing direct aircraft routing, improved jet engine reliability, and other technologies are deployed.

The process structure undergirding this view is described in Figure 4. There is basic research that generates a storehouse of knowledge, applied research and development improves the capabilities of suppliers, and cheaper, faster, better products are the result.

In a large part, the R&D process is energized by competition as suppliers seek to maintain or increase markets. Governments enter only when there are special circumstances.



Energy, safety, and environment issues have seeded some government action. Direct support of R&D for defense or national scale competitive purposes, R&D with respect to standards where new information is needed for setting or meeting standards, and support of development work prior to commercialization are other examples of cases where governments have acted



Figure 4. How Research and Development By Suppliers Builds From Basic Research to Create Improved Products.

Reasoning aligned with the process said that transit equipment manufacturers' failures to achieve technological advances were responsible for decreases in transit ridership in the US. Actions to force technological advances stressed the economic viability of equipment suppliers and transit agencies and delayed taking market-share-oriented adjustments

One cannot fault the research-improves-products reasoning because it is supported by many telling examples. Along with curiosity, it is the motive for mapping the human genetic code and space exploration. At the same time, many examples question the necessity of research as a preamble to innovation. After all, Stephenson's locomotive and other applications of steam power and use of materials preceded inquiry that led to concepts of thermodynamics and strength of iron or steel bridges

There is also the view that supplier actions drive demand. It is said, for example, that the demand for automobiles is driven by annual model changes. Supply push thinking is at work when the success of the railroads is attributed to Stephenson's locomotive. Air service is attributed to the Wright brothers' aircraft, but much more was required. In addition to aircraft improvement and market evolution, other technology components required development--

components such as airports and air navigation and communications systems.

It is too bad that Aristotle's insight, "All men by nature desire to know," isn't sufficient to motivate the funding of basic research. It is too bad that the serial reasoning--basic research leads and applied research and development follows--so often pushes ingenuity and innovation out of the equation. Indeed, much of the transportation experience says that innovation and successful services begin to emerge and then provide direction and resources for the energizing of R&D programs. That experience is ignored in many funding programs

## 5.2 Process Technology Improvements

Actors within supplier organizations might properly say that concentration on product technologies (lubricants, materials, fuels, engines, roads) slights the role of process technologies--the ways things are done. They might point out, for example, that putting 10,000 or so parts together to make an automobile or making patterns and cutting and shaping steel pieces and then fitting them into a ship represents a know how, a technology. Their point would be well taken

Process technology is much more than ways to organize production in manufacturing plants. It extends to institutional organization, understandings of when to make or buy products, and risk-taking skills when anticipating market trends. Considering the regional organization of production, the production-supporting infrastructure, such as banks and trade schools, may be regarded as part of process technology.

Transportation's process technologies have been widely imitated. The US Federal Highway Administration has served as a model for government delivery of physical infrastructure. It is said that railroads formed the model for the modern industrial organization. Transportation- and control-based lean production provides an example of a user-developed

innovation of wide applicability.

Looking back, product technologies appear to lead the development of process technologies. Technologies such as the container and the container ship and the automobile emerge, find markets, and are honed into a rather standardized/workable form. Learning about markets, market segmentation, processes suited to physical production, tailoring services to market segments, and government relations appear to lag the identification of workable products.

### 5.3 Market Driven Improvements

Section 4 dealt with user/market-driven technology improvements. However, that topic needs to be revisited in the context of suppliers' perceptions for many suppliers are user oriented. They undertake market surveys, monitor trends, and engage in focus group analyses. Suppliers interact with service providers using information from these sources, as well as information about competitors' plans. Indeed, air service providers, freight railroads, and some of the other modes depend heavily on information from suppliers when preparing business plans.

Safety and other regulatory requirements constrain and shape markets, so such requirements may be thought of as a variety of market-driver.

The process model describing suppliers' actions has already been displayed (Figure 4), and while the process shown holds, the perception it conveys may in many cases have an adverse effect on technology development. There is the presumption that the improvement to be made is known, all that is required is the investment in R&D to make it come true. This ignores the mutual learning engaged in as suppliers offer new products and service providers and users respond.

Recall that the diesel locomotive first emerged in the 1920s and 30s as a energy-saving

substitute for steam locomotives used for switching. It's subsequent development was steered by learning and innovation by equipment suppliers, rail service providers, and users of rail services. Today's 6,000 hp locomotives and the kinds of services they support are products of innovations pulled by market interaction and learning. Modern aircraft, container liners, and highways all result from interactive learning processes (Figure 5).

Suppliers Provide a First Approximation of A  
Desired Product or Process. Product Improving  
R&D Begins.           I  
                                  I

Service Providers Adopt as a Substitute They  
Begin to Find New Markets.

I  
I

Suppliers Refine Their Product to Track on  
Expanding and Evolving Markets. R&D Enhances  
Products and Opens Opportunities for User  
Innovations. Process of Production Improvements.

I  
I

Learning Continues.

Figure 5 Market Interactive Product Development.

As already mentioned, in spite of the presence of learning processes of the sort described in Figure 5, it is routine for R&D actors to engage in careful specification of problems/opportunities as they see and value them. This is one of the ways interest group politics steer R&D funding. That's too bad because interest group politics may limit imagination and thwart progress

#### 5.4 Economic Development Driven Improvements

Just as industries of all sorts invest in research and development in order to maintain and improve their competitive advantages, nations invest to promote economic growth and employment and to improve the health and welfare of their citizens. There is considerable activity. In the more developed nations, government and industry R&D expenditures of all types vary around 2% of gross domestic product (GDP) (In 1995, e.g.: Japan, 2.8%, US, 2.5%, Germany, 2.3%, UK, 2.0%, European Union, 1.6%.) Government expenditures on R&D are usually less than 1% of GDP. (In 1998, e.g.: Japan, .7%, US, .76%.)

It is to be expected that the larger the industry activity the larger the expenditure, and this expectation is born out by data on expenditures on transportation R&D (Table 2) Expenditures are dominated by the activities of aircraft and motor vehicle manufacturers, and in nations where these activities are large, expenditures are high. Some seeming peculiarities in the data are readily explained. When per capita expenditures are examined, for example, Canada has relatively low expenditures. Yet Canada and the US have about the same percentages of their labor forces employed in the transportation industries. The seeming peculiarity is likely because much of Canada's transportation employment is in US-owned corporations.

Table 2. Transportation Research and Development Expenditures, 1995

Country	Expenditures <sup>a</sup> (1995 \$US x 10 <sup>9</sup> )	Per Capita Expenditures
USA	37.4	\$145
Japan	18.9	150
Germany	9.7	118
France	6.9	117
UK	4.7	80
Italy	1.9	33
<u>Canada</u>	<u>0.8</u>	<u>26</u>

<sup>a</sup>Reported in "Comparison of International Transportation R&D Expenditures and Priorities," by Mark Stanford and Kant Praised, Volpe National Transportation Systems Center, Cambridge, MA, July 1999.

Even though R&D subjects are quite variable among nations and sponsoring organizations, a look around reveals that transportation looms large in R&D activities. In Japan, for example, government and industry R&D expenditures on motor vehicle, aircraft, and shipbuilding are about two thirds of those on communications, the industry leading in expenditures. In the US, transportation equipment leads other industry categories, followed closely by chemicals-pharmaceuticals and electrical equipment. Expenditures by the three major automobile companies are about \$18 billion per year.

Government expenditure patterns are variable among nations partly because of varied roles and traditions. Sometimes government expenditures promote new industries. The German government, for example, invests R&D funding in magnetic levitation, high speed rail, and road transport information. Competitiveness and the management of environmental and energy issues are considerations in many programs. For instance, the Japan Ministry of International Trade and Industry (MITI) has undertaken the development of ceramic components for a turbogenerator aimed at hybrid electric vehicle applications. The Italian Agency for New Technology, Energy, and the Environment is also supporting R&D on electric vehicle related subjects.

In the 1920s and 30s The US National Advisory Committee for Aeronautics developed low drag cowling for air cooled radial engines and it encouraged swept wing jet aircraft in the 1940s. Environmental enhancement, increased fuel efficiency, and jobs-competiveness have motivated the Partnership for a New Generation of Vehicles (PNGV) in the US. Established in 1993, expenditures have been about \$250 million per year. By 1999 DaimlerChrysler had received almost \$20 million in funds and 40 of the 114 private contractors had received \$1 million or more. Concept cars were announced by DaimlerChrysler, Ford, and General Motors

in 2000 and prototype 80 mpg vehicles are to be available by 2004.

Expenditures per capita are shown in Table 1 in order to to place perspective on programs. At about \$250 million per year, the US PNGV program is expending less than \$1 per capita per year. The US Intelligent Transportation System (ITS) program was funded in 1991 legislation at about \$3 per capita. Such magnitudes are small when compared to federal R&D annual expenditures of about \$80 billion or about \$300 per capita.

Several decades ago in the US it was thought that new technology would arise from major government programs such as those that advanced radar and atomic energy development. Perhaps the small size of the ITS and PNGV programs suggest a trend away from such programs to a more private industry, individual entrepreneur orientation.

The literature on R&D activities reveals a thrust toward competitive success and jobs (Figure 6). Other thrusts respond to calls for fixes on problems such as safety and pollution emissions. There is work with testing priorities, as well as work aimed at standards setting

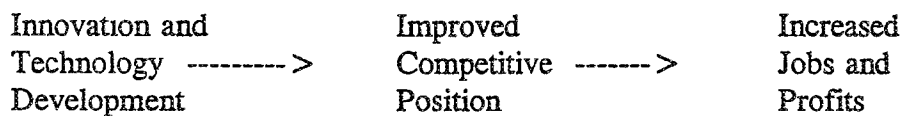


Figure 6. How Technology Development Improves the Competitive Positions of Firms and Nations.

The focus on suppliers to the exclusion of other considerations is unfortunate because improvements in transportation technologies have wide-ranging ramifications. It is what technology improvements do for users that is of overriding importance? Increases in suppliers' jobs and profits may have little relation. They may impose increased cost burdens on the general public or on service providers and users, as has been the case when over build (or poorly designed) facilities such as inland waterways, ports, subway lines, and airports are promoted and

when nations act to protect industries from competition Wellington's comments on railroad construction apply In late 1800s he remarked on routes that were "bleeding and oozing from every pore," but with dysfunctions not recognized. The emphasis on jobs created by suppliers to service providers leaves room for many unrecognized dysfunctions.

## 6. Service Providers As Innovators

Service providers combine inputs to meet demands by users, and the services provided are identified using a modal language There is reference to transit, automobile, tankship, pipeline, highway, air, short sea, walking, and other forms of transport. These modes provide services by combining operations protocols, fixed facilities, and equipment. Those are the basic building blocks and, in turn, they combine other building blocks

Many service providers are individuals. They pilot small planes, walk, sail, or drive cars and trucks. In other situations there are providing organizations, but some self-provision is present in most all passenger services. The air trip, for example, involves the traveler making route and schedule decisions and navigating to and from airports and within them. The train or bus trip usually involves a walking connection, as well as decisions about when and where to travel

State-owned or private railroads offer train services. Firms provide air and trucking services, and state or privately provided bus and ferry services are available. Providers may differentiate their services by type of market or geographic area

Although service providers may not think of their having roles in innovation and technology development, many are very much involved in such matters. The more innovative they are at their tasks, the better the services they provide. Where competition is present, as in



the cases of container liner, air, and trucking services, innovation is key to successful competition. Competition is less of a force in some other endeavors. At the individual travel level folks often seem to cope rather than compete, they strive to travel in the most rewarding (to them) fashion. Where governments provide services, agencies give priority to their visions of efficiency and needs for services.

### 6.1 Service Innovations

Whether a bullock hauling a cart, barges in a tow, or some other arrangement, equipment controlled in some fashion moves on facilities, and, as stated, providing service involves combining three technological components: facilities, equipment, and operations protocols. The organization charts of railroads provide a striking example of this structure: the three major divisions are operations, way and structures, and equipment. The divisions are just as real in other services where organization charts are not generally found and functions are fragmented among institutions and actors.

Ocean transport makes use of docks and navigation facilities, ships of many types, and operations protocols involving tariffs, contracts, navigation and rules of the road. Oceans, canals, and dredged harbors provide the guideways. Air services are provided by firms using airports and airways, air traffic control services, and many types of aircraft. Taxi service providers purchase or rent equipment and operate it on publicly provided roads according to norms for fares and the scope of services.

Figure 7 shows service providers using fixed facilities, equipment, and operations protocols to produce services. That can be thought of as a first step, the second step (not shown) is the recognition of market response and the refinement of the ways services are configured.

The feedback from the market extends to suppliers-to-service-providers and they tailor their products to emerging markets.

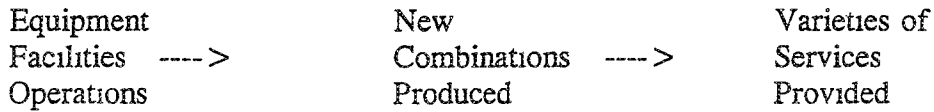


Figure 7. Service Providers Combine Inputs to Produce a Variety of Services

### 6.1.1 Examples

The innovations yielding the modern modes are readily recalled. Railroads emerged when George Stephenson combined the steam locomotive, tramways and the wagons they used, and canal and tramway operations protocols to haul coal from Stockton to Darlington. Those were the basic elements. Much more was involved, of course. Railway operations protocols extended the commodity classification and tariff system used on canals, facility construction made use of contracting firms and construction techniques with canal and port experiences, and financing was arranged by organizing a stock company and obtaining loans.

Electric streetcar services combined railroad-like trackage and emerging electric power generation and distribution technologies, railroad and horse drawn vehicles, electric motors, and other things. The modern auto-highway system emerged by combining existing highway facilities, motorized buggies (automobiles), wagons (buses and trucks), and bicycles (motorcycles) with rudimentary rules of the road.

Such combining/innovation continues. Nowadays, 350 gross ton trucks operate on simple roads within open cut mines and robots deliver mail within offices. Mobile robots perform tasks within manufacturing plants, and helicopters or lighter-than-air craft move logs from remote forest locations.

Experience after experience such as these highlight the combining of old and new building blocks and the rudimentary aspects of systems early on. They underscore the importance of market niches and tell us how improvements on old services and new ones disrupt previous services

### 6.1.2 Variety and Qualitative Change

To visualize changes in the ways transportation services have supported society's advances, imagine a contest which asks that names of transportation services be written down the middle of a page.

What names appear? A contest participant might proceed by thinking of a mode and listing its varieties, say, trains, and then chemical, merchandise, sweeper, container, merchandise, heavy haul, and passenger. That's identifying rail as a predominant technology and identifying variations that have emerged over the years. There is trucking, and varieties of trucking services might include tankers, reefers, and local delivery.

The experiences of contestants might shape answers. For some city folk jitneys, transit, and taxis might loom large, and bulk shipping, pipelines, and barges might come to mind for some in industry. Bullock carts or other animal drawn vehicles reflect the experiences of many. Most everyone walks.

Transport of electricity, of irrigation and potable water, belts moving ore in mines? Imagination will yield many kinds of services and ways they are provided.

Names were placed in the center of the page so that origins could be listed on the left and future services on the right. That arrangement highlights increased variety today compared to yesterday and, presumably, tomorrow compared with today. It reminds us that increased variety

is an overarching feature of technological change in transportation. Increased variety is transportation's response to changing social, ecological, and economic conditions, and by increasing variety transportation has enabled qualitative changes in production and consumption, trade in ideas and understandings, and society's management of problems

The increased variety story can be told for each mode. Trucks nowadays come in all sorts of sizes and weights and in varieties suitable for services ranging from moving plumbers and their tools to residential repair jobs through over-the-road, long distance freight hauling to equipment suitable for very heavy haul such as that of moving cracking towers to refineries

Increased service variety has much merit. It's too bad that standards, the desires of stakeholders to protect existing investments, lack of imagination, and the high cost of risk-taking often seem to thwart increasing variety. These things and others are symptomatic of the behaviors underlying historic path dependence.

### 6.1.3 How Variety Overcomes Historic Path Dependence

But from time to time variety has increased in spite of the constrained paths dictated by historic path dependence--development paths variegated, shifted, or bifurcated. Container services illustrate that point. In the 1950s the wisdom about the break bulk ocean liner operations of the times said that things were pretty good. The future would see marginal increases in ship sizes and cruising velocity and these would result in cheaper faster services. The important thing to do was to improve freight handling on docks and when loading and unloading ships one pallet at a time. This would shorten ship turn around times at ports and warrant the increased cost of modestly larger faster ships.

But some service providers saw container services in market niches as a possibility, and

after trial and error and market discovery, container services emerged and they are now well on the way to saturating their markets. The great productivity gains from container services resulted in new types of ships and docks, and the use of containers enabled new shipper activities--doing new things.

At about the same time it was thought that larger jet aircraft such as the Boeing 707 had a limited future because most airport terminals were too small and runways too short. Air traffic control procedures would not be favorable. But one service supplier had a market niche in mind and saw the aircraft as a viable proposition. The firm took risks and the market pulled changes in the services offered.

The recipe for increased variety emerges from experiences such as those for the container and air modes. There's combining of facilities, operations, and equipment, a beginning market niche and the discovery of new markets based on new uses; risk taking and the breaking of constraints; and other things. Sometimes actors can be identified, as is case for rail services and container and air services, but often many actors are involved, as was the case when auto and truck services emerged. No matter, the pattern is the same.

## **6.2 Venues For Service Provision Innovations**

Transportation takes place on networks consisting of links, intersections, and transfer nodes. The networks are a realizations of modal technologies, markets for innovation and technological improvements, and the mechanisms with which interactivity is performed. They play connecting roles.

The networks are formed by rivers and canals, ocean routes, rail lines, roads, airways, pipelines, roads and trails, and transit routes. But when connecting roles are considered, topics

extend well beyond facilities. The matching of services of different types to different places is at issue. Also, connections among physical networks require switching and other interfacing technologies

### 6.2.1 Network Interfacing Technologies

Connections are required among links and nodes, and such things as railroad freight car classification and interchange yards, bulk and container marine ports, passenger and freight airports, rail passenger stations, and truck freight terminals serve connecting purposes. Looking back, technologies aiding connecting were developed in the 1870s and 80s when the US Master Car Builders Association promoted rail car coupler improvements including automatic couplers. Centuries earlier, Chinese rulers had mandated standard gauge for cart wheel spacing so that carts would fit the ruts on the roads in different regions. Today's improvements in large airports hubs, container marine-rail-truck transfer yards and hubbing ports, and large automated freight car classification yards illustrate how connecting technology improvements continue to influence transportation services

Less visible but no less important are the "soft technology" protocols that aid flows on networks and from network to network. Centuries ago bills of lading and way bills were innovated to identify things moving and the routes for movement. Commodity classifications, tariff sharing, equipment rental and repair schemes, and other interfacing techniques also emerged.

Today, information systems, identification markers, such as bar codes and electronic tags, and routing optimization and scheduling algorithms join older protocols and make for user-friendly interfacing across physical networks, national boundaries, and from mode to mode.

Standards continue to serve interfacing/connecting roles. There are standards for air traffic control, highway signs, pavement widths, measurement of ship capacities, container sizes and weights, and endless other things. Government and nongovernment national and international organizations create and enforce such standards. But many standards simply represent accepted practice and the technology available at the times networks were put in place. They continue as matters of tradition and habit.

Standards aid connecting activities. They accelerate the diffusion of technology and assure its quality. But at the same time they occupy the turf, so to speak, and they may thwart motivation to improve old technologies or seek new directions for development.

Technology actions may address networks as a whole or access points, links, or interchanges. At a conceptual and analytic level, attributes such as queuing or storage, equilibrium flows, and network and link capacity are similar across infrastructure systems (electrical; drainage, potable, and irrigation water; wireless and land line communications; and sewage) and from mode to mode in transportation. It is too bad that historical, built environment, and institutional differences have compartmentalized technological concepts and may constrain imagination about technologies

### 6.2.2 Changes in Networks

As technology development and adoption recipes play out and markets respond, there are changes in networks and their use. Some networks have decreased in size. In nearly all networks there has been a concentration of traffic on routes, and the approximation that about 20 percent of the route mileage handle 80% or more of the traffic holds for rail freight, container ship, highway, pipeline, and air traffic routes. Technology development is oriented to dense traffic

routes, and light density routes where outdated standards make historic facility building and maintenance procedures inappropriate may be relatively neglected. When wagon traffic asked for improved roads there were abandonments of trail and paths and in recent decades the mileage of rail routes has been reduced. Technologies for similar network rationalization are available for other modes but are rarely imagined and implemented

Changes in markets and service availability yield changes in network flow equilibria and interactivity processes. There are adjustments of all sorts ranging from the ways urban travelers schedule their trips and select routes, through changes in industrial production and commodity flows, to advantaging or disadvantaging communities by altering their accessibility to resources and markets or damaging or improving their social and ecological environments. For an example from the past, the workmen's trains developed by early English railroads created new commuting patterns, often as not by the use of their tracks as walkways. Improved railroad service in the US Lake States seeded farm machinery manufacturing and supported commodity flows to eastern ports. Lower cost farm commodities and new patterns of trade adversely affected the ports at New Orleans, as well as New England farmers. It is always the case that some folks and places gain and some lose.

### 6.2.3 Access and Accessibility

With development driven by the search for markets, political ambitions, and equity considerations, networks of the modern modes had extended through a good part of the world by the middle of the twentieth century. The continuation of these forces and the efforts of international aid programs have extended the availability of networks, and all persons and places have some sort of access to networks. Today, transportation is regarded as one of the universal



input (infrastructure) industries necessary to modern life. Education, health care, potable water, and communications services are other such inputs.

Although extending and maintaining the availability of access seems mainly a matter of political will and financing, there are technological aspects including the development of more effective construction and maintenance techniques. More advanced challenges for technology include the acquisition of terrain data bases for ground proximity warning systems for remote, difficult-to-access airports and the development of sensors monitoring the condition of isolated pipeline facilities.

The presence or absence of access is one thing. Accessibility is another: some places interconnect more easily than others. Accessibility turns on the quality, cost, and variety of services that are available, as well as the interrelations of services with the markets they build and serve. The development and diffusion of effective technologies providing accessibility requires a consideration of the linkages that transportation services provide, as well as the enabling roles transportation play.

The tailoring of accessibility-providing technologies to market niches was an important feature of early transportation development. The Indiamen, Dutch trading ships, and North Atlantic packets were tailored to their trades, just as today's airline, ship, truck, and pipeline operators tailor equipment and services to markets.

Even so, market and other conditions bearing on accessibility are often ignored, and many view the presence of access to a facility such as an airport or a highway as sufficient for creating the developments contingent upon accessibility. That's too bad, and it is also too bad that "one size fits all" rather uniform technologies are imagined to be suited for any case, as was

the case when rural Interstate highways in the US were built to the same standards regardless of their environments.

## 7. Transportation/Communications Synergies

As remarked, communications technologies are being incorporated into transportation technologies. This is not an unexpected technological development, for the development of mail, telegraph, newspapers, telephone, and other communications instruments played roles in the unfolding of maritime, rail, air, and other services. Indeed, at the opening of the British Exposition in 1851, Prince Albert mentioned both communication and transportation when remarking on how historic barriers to accessibility had been overcome.

Transportation/communication services are complementary and supportive. Looking back it is seen that letters of credit were essential to the early ocean trades. More recently, the development of international air package services was accelerated by the advantages of having ship-lading information prior to ship arrivals.

There are also competitive aspects. Early railroad managers feared that the telegraph would decrease rail passenger trips and agencies managing congested highways were hopeful that telecommuting would ease commuting demand. It is too bad that such fears and hopes have oversimplified the relations between communications and transportation.

The more important synergies emerge when transportation and communication technologies serve as building blocks enabling reshaping old activities or creating new activities. The telegraph-railroad based emergence of large scale continuous iron and steel production is an example from yesterday's experiences and the emergence of business-to-business internet markets is suggestive of today's developments.

**SUMMARY**

Looking back and looking around reveals that technology development is undertaken by actors in overlapping roles. There are (1) suppliers such as shipbuilders, highway and bridge agencies and construction companies, and petroleum refineries, (2) service providers such as railroads, liner operators, and individual auto drivers, and (3) service users such as manufacturers and farmers and folk traveling for varied purposes. Prior to discussing activities in these sectors of transportation enterprises, a general model of technology development was presented. The constraints on technology development imposed by the incremental and historic path dependence behaviors of systems were identified.

The discussion emphasized the ways transportation innovations and improvements have increased the options available to users. As the variety of available services has increased, users have improved the ways old things were done and begun to do new things

But technology development is mainly viewed and undertaken in a rather myopic fashion. Actions taken are constrained by views of the processes of technological change and their consequences that adhere to the division of transportation enterprises into supplier, provider, and user segments. Another dysfunction is the failure to recognize and seek the innovation enabling, option opening, quality of life enhancing consequences of improved transportation services

**BIBLIOGRAPHY**

Andersson A. E. (1986). *The Four Logistics Revolutions, Papers of the Regional Science Association*, Vol. 59, pp. 1-12. [Identifies and interprets great waves of transportation-communications-enabled economic and social development]

Bruno L. C. (1993). *On the Move: A Chronicle of Advances in Transportation*, 423 pp. Detroit, Gale Research Inc. [Exhaustive list of innovators, events, and artifacts]

Burg, v. d. G. (1969). *Containerisation: A Modern Transportation System*, 319 pp. London,

Hutchinson & Co. [Evolution of ships and containers; air and surface transportation relations. Documentation, economics, and labor considerations. Snapshots of innovative pioneers]

Frybourg, M. ed. (1987). *L'innovation dans les transports*, 133 pp. Caen, France, Paradigme. [Essays on innovation in transportation and relations to political-institutional structures and supplying industries. Commercial activities and intercity rail and public transit emphasized]

Gardiner, R. G. ed (1992) *The Shipping Revolution: The Modern Merchant Ship*, 208 pp. Conway Maritime Press, 1992. [Illustrates the variety of modern ships]

Garrison, W. L. (2000). Innovation and Transportation's Technologies. *Journal of Advanced Transportation*, Vol. 34, pp 31-63. [Historical overview and assessment of technology development processes]

Garrison W. L. and Ward J. D. (2000). *Tomorrow's Transportation: Changing Cities, Economies, and Lives*, 316 pp. Boston, Artech House. [Innovation and its consequences. Evolution of the modes. Opportunities]

Grubler A. (1990) *The Rise and Fall of Infrastructures: Dynamics of Evolution and Technological Change in Transportation*, 305 pp. Heidelberg, Physica-Verlag. [Analytic treatment of examples of system development and diffusion, competition, and interrelations of US and European transport and communication systems]

Heppenheimer, T. A. (1995), *Turbulent Skies: The History of Commercial Aviation*, New York, John Wiley and Sons, Inc. 1995. [Beginnings through the jet age. Treats aircraft, airports, navigation, and firms]

Hilton, G. (1990). *American Narrow Gauge Railroads*, 580 pp. Stanford, CA, Stanford University Press. [Describes how rail technology was adapted to market niches]

McShane, C. (1994). *Down the Asphalt Path: The Automobile and the American City*, 384 pp. New York, Columbia University Press. [Evolution of the urban modes, expansion of urban areas, popular culture]

Owen, W. and Bowen, E. (1967). *Wheels*, 200 pp. New York, Time Incorporated, Life Science Library. [From early technology to modern times, scoped to all modes and social relations]

Sahal, D. (1981) *Patterns of Technological Innovation*, 381 pp, Reading, MA, Addison-Wesley. [Concepts of technology, diffusion, life cycles, general principles. Aircraft, locomotives, railroads, and tank ships used as examples]

Smith, C. O. (1990). *The Longest Run: Public Engineers and Planning in France*. *American*

*History Review*, Vol. 95, pp. 657-692. [Applications of technical-organizational expertise to canal, rail, and highway systems]

Summerton, J. ed (1994). *Changing Large Technical Systems*, 348 pp. Boulder, CO, Westview Press. [Many aspects of changes considered. One chapter discusses how transportation services entered the innovation and operations of the European organ donor system]

Szostak, R. (1991) *The Role of Transportation in the Industrial Revolution A Comparison of Eighteenth Century England and France*, 337 pp. Montreal, Canada, McGill-Queens University Press [Emphasizes how service improvements stimulated innovation]

Vance, J E. (1986) *Capturing the Horizon The Historical Geography of Transportation Since the Sixteenth Century*, 656 pp. Baltimore, MD, Johns Hopkins University Press. [Emergence and diffusion of systems; relations to settlement patterns]

Ville, S P. (1990). *Transport and the Development of the European Economy, 1750-1918*, 252 pp. New York, St. Martins Press. [Diffusion of modern systems and ties to industrial development]

Willson, B (1913). *The Story of Rapid Transit*, 237 pp. New York, D. Appleton and Company. [Traces development of the modern modes]