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USING TECHNOLOGY TO IMPROVE TRANSPORTATION SERVICES

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USING TECHNOLOGY TO IMPROVE TRANSPORTATION SERVICES

Abstract

Today's transportation systems are well deployed in the developed nations, and they and their supporting activities are technologically and institutionally mature. This situation is exceptional in the perspective of the last 200 years of transportation development, during which new systems were innovated and wave after wave of construction undertaken.

An examination of the ways technologies were shaped and adopted in the past reveals that today's view of technology-based opportunities is also exceptional. Consistent with system maturity, the search for improvements is focused on marginal changes in service quality or decreases in costs. Electronics technology, for example, is being applied to smooth highway traffic, improve microwave aircraft landing systems, and tighten shippers logistics' systems. Such marginal improvements were, of course, sought in the past. The difference then was parallel interest in new system or subsystem designs. In the context of these designs, marginal changes yielded revolutionary system improvements.

The maturity of today's systems coupled with rapid expansion of technologies of possible application push and pull for increased emphasis 'on embodying technologies in new system designs.

This analysis has the overall objective of treating how improvements may be made in the ways technology is innovated, developed, and applied to transportation. Toward that objective, it begins with a discussion of product life cycles and how the life cycle concept applies to transportation services. Making use of examples, it then positions each mode within its life cycle. Emphasis is on changes in technology applications as systems move along their life cycles; it is also on how technology-induced service improvements vary.

At that point in the analysis a secondary objective of this work will have been accomplished, for a statement of the several ways technology is applied to transportation will have been achieved.

Today's technology work is then examined. As is well known, there are vigorous efforts to incorporate new and emerging technologies in transportation. The U.S. railroad equipment suppliers are designing integral trains, and railroads are designing and deploying advanced technology control systems. Ultrahigh bypass and unducted fan engines are under development for aircraft. Automobile producers, trucking firms, and highway organizations are looking into the applications of sensor, information, and computer and control technologies. Methanol fuel use is under study. Lubrication and materials advances are being widely applied, and there is emerging interest in the application of potential superconducting materials. The list goes on.

To critique current work, long term trends in system improvements are examined with emphasis on the automobile and air systems. Current work is also placed in the context of product life cycles. The not unexpected conclusion is reached that today's work is of great value. Even so, the work lacks the attributes that induced major transportation improvements in the past.

The final section of the paper provides suggestions for work on smart vehicles and highways, bulk commodity shipments, and truck- and auto-only highways. These suggestions highlight attributes of broadly scoped work, work similar to that successful in the past.

This analysis is undertaken for two reasons. First, it is background for technology assessments underway by the author (Garrison and Taff, 1988; Garrison, 1987a and 1987b). Second, the transportation industries are a not-so-small part of the troubled mature industries of the developed nations. For reasons to be discussed, improvements come hard in mature industries, and there are constraints on their uses of new technologies. Mainly, they seek technologies that fit and marginally improve a given structure of activities, technologies limited in variety and efficacy.

Might there be strategies for technology innovation, development, and implementation that break the tyranny of maturity? The discussion to follow will emphasize innovations embodied in system designs and tried out in market niches.

The Transportation Technology Life Cycle

The life cycle concept has long been used by technologists and managers of research and development, and it is increasingly used by managers of firms and policy analysts (Ayres and Steger, 1985). It applies to products, and it uses a biological language. A product is conceived as an idea and birthed as a prototype. With subsequent refinement, it begins to be adopted by markets. Eventually, a rather standardized product saturates the market, senescence is boded when sales are mainly replacement ones or when competing products begin to nibble away markets.

Transportation Systems:

Application of the life cycle concept to transportation appears straightforward. Indeed, transportation products are often used to illustrate the concept. There was the railroad steam engine development cycle and its replacement by diesel or electric propulsion. The Model-T Ford ran a life cycle until abruptly replaced by competitive products. The highway system in the U.S. is widely regarded as mature, standard designs have

River steamboat come to mind. In each case, designs were system scoped. They involved a guideway and other fixed facilities, equipment, and uses/operations.

The birthing of a system is usually associated with equipment development--Fulton's steamship and Stevenson's locomotive for example. The Model-T Ford and the Douglas Corporation's Model-3 (DC-3) are also cited. But closer examination underscores the importance of system design in market niches. For one thing, one can almost always find workable equipment available prior to system birthing. Steamships, locomotives, containers, and automobiles were available before successful system designs were found, sometimes available for decades. System innovations required more than equipment. They incorporated fixed facility, equipment, and operations hard and soft technologies in successful designs in market niches.

Reference to the air and automobile systems introduces another aspect of system birthing: Sometimes designs emerge from the workings of somewhat independent actors. Adding to development of the DC-3 for the air transportation system, actors involved with airports, airways, navigation aids, airline firms, government and users all contributed to the innovation process. Highway builders, users, and other actors played their roles in the development of the auto-highway system. In addition, the development of these systems occurred in multiple market niches. The auto was a rich man's toy in many cities and soon a workhorse on farms, for example.

So while convenient for short hand description, the tieing of an innovation to equipment development slights the system design process. This point will reemerge in the last part of this discussion when suggestions for technology development are discussed.

Growth and Development:

Once the idea of the system is demonstrated as a prototype, improvements are rapid. The design itself may be modified, as was the case when the Liverpool and Manchester, London and Birmingham, and Baltimore and Ohio railroads eliminated many of the tramway features and modified the common carrier aspects of the Stockton and Darlington. But by-and-large the system design changes little, and improvements are made at the level of the systems parts.

Although a limited snapshot, Figures 1 and 2 showing information on Atlantic liners illustrates the pattern of improvements. The passenger and priority freight liner system dates from about 1838 when Brunel introduced the Great Western accompanied by shipbuilding, dock, and organizational developments. As materials became available, ship construction shifted from wood to iron to steel. The engine-propulsion system shifted from paddle wheels to multiple screws; simple steam engines added expansion cylinders, and then gave way to turbines. Velocities increased with more efficient powering, and, as markets grew, liners were increased in size to achieve scale economies. The technologies provided for service improvements of a factor of two or greater.

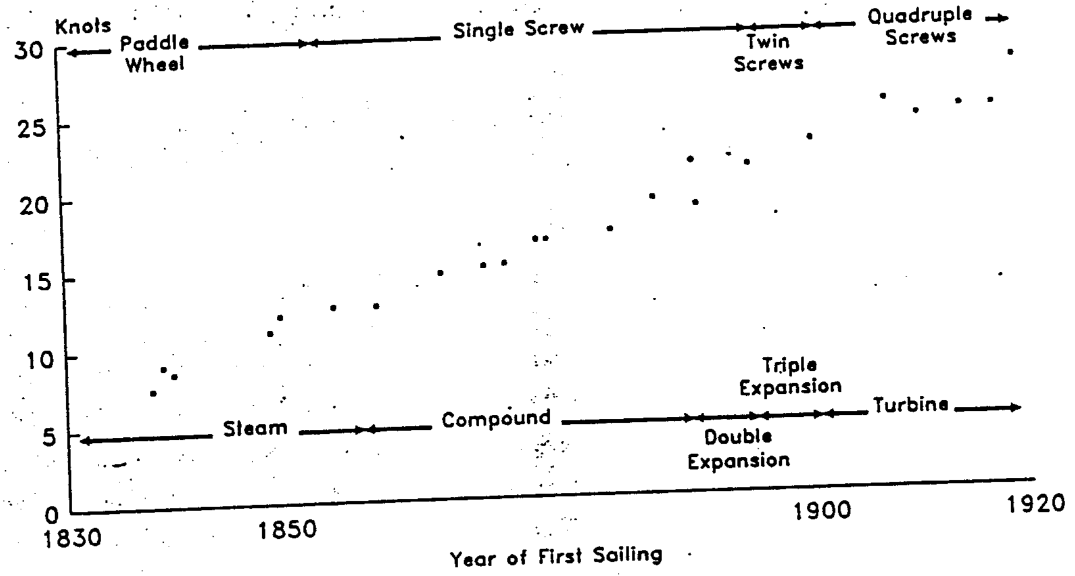

Figure 1: Evolution of the Atlantic Liner, 1838–1914 : Speed *
* Data from Zimmermann, 1923

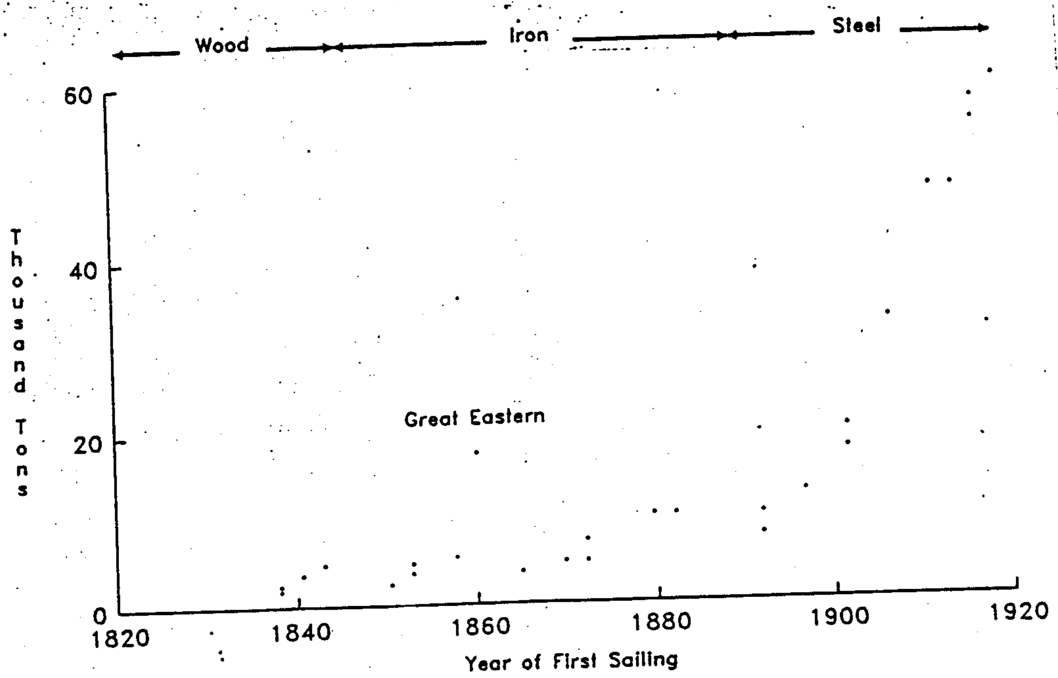

Figure 2: Evolution of the Atlantic Liner, 1838–1914: Tonnage *
* Data from Zimmermann, 1923

During this same period, the other parts of the system also improved. Insurance arrangements were modified. In the search for safety, bulkheads were improved (but not enough to prevent the Titanic disaster), and the Plimsoll Line was introduced. Port, navigation, and other improvements continued.

The pattern, partly illustrated by the liner example, is that of some revision of the system design early on, but mainly the pattern is that of hard and soft technological improvements specific to parts of systems. Taking the system design as a given, technology is developed and introduced to improve system parts. The pay-offs may be lowered costs or greater reliability. There may be service quality improvements.

Another source of pay-offs is from economies of scale and scope. The introduction of the diesel on railroads illustrates the pattern. There were immediate pay-offs from reduced fuel and maintenance costs and increased reliability. In the longer run, the diesel allowed longer run-throughs increasing the areal scope of service improvements, and diesels operating in multiple units permitted increased train sizes and weights and achieved economies of scale on dense haul routes.

Maturity:

Systems eventually mature by saturating their markets and hardening their technologies. Standardized services are everywhere available, and growth or retraction of service responds to gross market size. A good part of the fates of automobile and transit services in the United States in recent decades is as simple as that.

The technologies become rather frozen or hardened in part because the higher pay-off technologies are introduced early-on and diminishing returns set in. That explanation is partial, because work by scientists and technologists has exponentially increased the supply of technologies that might be applied.

Three other explanations apply. As mentioned, technologies are introduced to capture scale and scope economies. When the market is saturated, the opportunities for scale and scope gains are dampened, although competitive processes may encourage variations in technologies suited to particular market niches, and the gross market may be growing. That is the case in air transportation, where airport facilities, modes of operations of firms, and aircraft are tailored and retailored to get scale and scope just right.

In addition to affecting equipment and fixed facility technologies, scale considerations greatly affect process-of-production technologies. Except for product variations tailored to markets, such as deluxe automobiles versus standard ones, mature products are standardized and compete mainly on price/quality attributes. Cost reduction turns on appropriate control and capitalizing of the production process for efficiency at the size of market. Introduction of a radical process-of-production or product changing technology is, thus, inherently risky. If a process-of-production technology fails to perform as projected, it may have adverse affects on production costs. If the product fails in the market, scale efficiencies in production may be lost.

The third point considers barriers flowing from system structure. Each part of the system is honed to produce the product, and a change in any part is locked in by requirements that it work with other parts. A concomitant of the standardization of system products is the development of industry, government, and association standards, and these are sharply limiting.

Lessons:

The consideration of the life cycle highlights quite different roles for technology as systems move along the life cycle. Early-on, the task is that of embodying technologies in system designs. That is an integrative effort that uses building blocks where ever they can be found; its a try out a design in a market niche activity. It treats system parts as clay and it molds them (Sahal, 1981).

Once a successful prototype is found, technologies are introduced to modify designs and, especially, to improve system parts. Gains in system performance are rapid as the system begins to be deployed and scale and scope economies are achieved.

But as "best," standardized designs are found and as the market trends toward saturation, a system is more-and-more locked-in by its structure and by standards and regulations preserving that structure. The best things to do have been done, and much of scale and scope economies have been found. More-and-more, windows for technology applications are limited.

Finally, the system matures as a standardized design fills the market. Technology is restrained to low risk applications conforming to system structure. It tends to be focused on product cost and performance attributes and/or differentiating a standardized product to market segments.

What is Technology Doing for Today's Transportation Systems?

Against the backdrop of lessons from consideration of transportation life cycles, what's the situation in today's transportation systems? How is technology contributing to transportation improvements? What windows for technology applications are available? What should be expected of technology? The life cycle concept is general, specifics are needed.

We will deal with these questions in three steps. First, today's situation will critiqued through reference to an expert, consensus study of technology developments. Second, current and expected contributions to improvements will be explored using two modal cases, auto and air transportation. Finally, brief comments will be made on other modes.

Large questions such as those to be explored never answer easily, and there is sufficient diversity among the modes that answers that fit all modes well fit none exactly. Furthermore, a convincing argument is difficult because it yields a counter-intuitive result, and one that isn't flattering to industry managers and technologists: Today's work isn't inducing gains comparable to those of the past, and there is good evidence that expectations about technology should be modest unless improved strategies for development and implementation are adopted.

The Situation:

In 1982 the National Research Council in the U.S. included a chapter on transportation in its **Outlook for Science and Technology: The Next Five Years** (National Research Council, 1982). The short time frame of the projections and near-concurrence of the time period with today suggest that the chapter provides expert judgement of current developments. The developments summarize:

1. Microprocessors used for automobile engine control extended to highway traffic control for flow improvements. Route optimization and off-board vehicle control may evolve later.
2. Higher speed helicopters for several hundred mile service.
3. Supersonic aircraft.
4. Vertical/short take-off and landing aircraft for relief of airport congestion.
5. Improvements in the air traffic control system; improved in-cockpit devices.
6. Advanced design, large scale bulk carriers for the Great Lakes.
7. New rail equipment for intermodal service.
8. Technologies to reduce stress on railroad rail.
9. Improved intermodal system management techniques.
10. Improved dewatering and use of fluids other than water in slurry pipelines.
11. Energy efficiency improvements in vehicles from reduced weight and aerodynamic, powertrain, and engine improvements; lighter, stronger materials.
12. Development of alternative fuels.
13. Reduced atmospheric and noise emissions.

Leaving aside the points that a different study committee might have produced a somewhat different list and that some of the listed developments have not yet appeared, what signals is the list sending?

Equipment development dominates the list, and technologies embodied in products rather than processes-of-production also dominate. We hesitate to draw a conclusion from this observation. Equipment is largely produced by competitive firms, and such firms seek visibility for their work; equipment is much discussed. Also, there is a tendency to associate technology with physical products, and especially equipment rather than fixed facilities or operations.

Leaving the equipment emphasis aside, three factors to which technology is responding may be identified. First, there is work to improve service in existing markets by specializing equipment to markets, especially aircraft.

A second factor is the availability of new technologies, microprocessors and materials, in particular.

Finally, there is response to changes in the prices of inputs, operations costs, and the costs of output externalities. Real or anticipated increased energy prices press many of the developments; there is response to congestion problems and pollutant and noise emissions.

Perhaps the appropriate summary statement is this: There is use of technology to manage problems and to tailor services to markets. Problems include changes in factor prices, congestion, and undesired externalities.

Two additional questions will now be treated. First, how do the technologies relate to stage in life cycle? Second, what pay-offs should be expected from use of these technologies.

Technology and Life Cycle:

The discussion of the life cycle pointed out that systems birthed as designs incorporate fixed facilities, operations, and equipment in market niches. None of today's technology developments appear to have that potential. Three, intermodal, supersonic aircraft, and helicopter developments, may have that potential if embodied in new system designs.

Once birthed, there are rapid improvements in technologies for the parts of systems, improvements of a factor of two or more, as the development of the Atlantic liner illustrated. As technologies are standardized and as systems increase their markets, economies of scale in production and operations are critical, and technologies are sought that aid achieving economies of scale. None of today's technology developments are sharply pulled by these "best, standardized" or "economy of scale gaining" purposes; none run the risk of running counter to the purposes.

As markets near saturation or become saturated, the manager's problem is that of tailoring services to market segments to the extent that is possible with standardized product and process-of-production technologies. Managers also seek to lower input factor prices and to adjust to changes in their environments in order to remain competitive. Problems must be managed. Most of the technology developments noted respond to these requirements.

This partial conclusion is reached: Most of today's technology development is characteristic of mature systems. The conclusion is somewhat arguable because it involves interpretation and classification of developments. There is also a time-will-tell question, especially for intermodal and aircraft developments.

The conclusion that today's technology developments are characteristic of mature systems was termed a partial conclusion because there is another part to the conclusion. It is that the consequences of technology development will not be great. The "consequences will not be great statement" is a comparative one. Early in the life cycle the birthing of new systems and subsequent rapid technology improvements improve services or lower costs by a factor of two or more, as mentioned. Though limited in impact by this comparison, today's improvements are worth pursuing, of course.

Consequences of Today's Technology Developments:

At this point, the statements just made about the consequences of today's technology developments are assertions. To flesh them out, the situation in the auto-highway system will be examined in some detail, short remarks will be made on the air system, and summary sentences will be given on the other modes. Space prevents treating all the modes, and it limits what can be said about the modes taken as cases.

The Automobile Highway Case: Trends. Considering the automobile-highway system, its history and its technological history, in particular, are well known. In the U.S., the road part of the system began to be improved to accommodate the automobile during the 1910s. Cities developed protocols for the delivery of roads and streets. Arterial and local access road classification and design standards emerged by the 1920s. Urban institutional and financing schemes were developed.

Rural roads began to be improved using designs, surfaces, and structures suited to the automobile. Roads that were at best Telford-macadam designs were improved as the federal and state governments assumed responsibility for the state systems, at first, seven per cent of rural mileage. Counties or other local governments began to improve other rural roads.

Building from proposals during the 1930s for regional defence and toll road highways, the interstate system was implemented in 1956. Its mileage is largely rural, however, urban extensions of the interstate and other freeway facilities were constructed in the urban areas.

Steam powered automobiles (and busses) were tried out beginning early in the 1800s, and steam, electric, and Otto cycle engine vehicles began to find markets during the first decade of the 1900s. In the American market, Henry Ford's Model-T was introduced in the 1910s. It set the pattern for a mass market vehicle (Otto cycle engine, naphtha fueled, four wheels, engine in front, alloy steel) produced using standardized parts and mass production methods.

Traffic control technologies aiding the use of the system also emerged in the early 1900s, and they were refined as users developed the know-how for system use.

At first the automobile was a good weather, rich man's toy. In the 1910s, the Model-T began to replace the horse and wagon in rural areas, and urban users began to organize work, social, and other trips using the automobile. By that time, suburbanization, outlying shopping centers, and other features of the city reflecting automobile dependence began to emerge.

Although the timing differs from nation to nation, the pattern of the emergence of system parts holds among the developed nations. Its a well-known story, but not one that delves deeply into the stage in life cycle of the system, its use of technology, or its performance.

Stage in life cycle can be deciphered by examining the evolution of system parts. The highway system is shown in Figure 3. Needed was a product suitable for automobile use, and hard surface pavements are one attribute of such a product, although that measure does not catch highway quality improvements, e.g., wider lanes, as development proceeded. Figure 4 provides a fragment of information on the deployment of high capacity, high quality facilities. Although facilities continue to be built, freeways have saturated their market in Los Angeles.

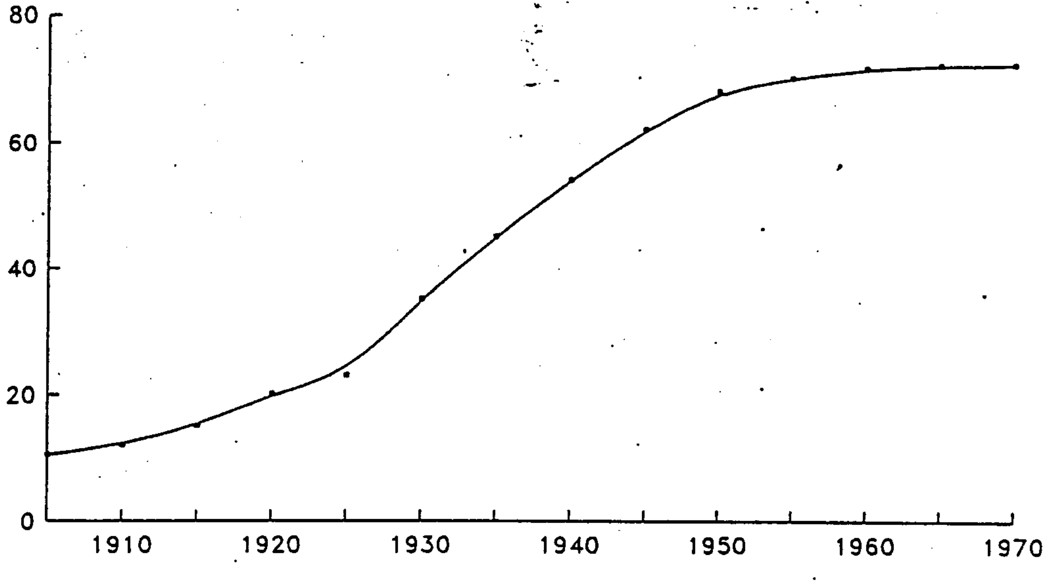

Figure 3: Linear Feet of Paved Road Per Capita: 1905–1970 *

* Data from U.S. Department of Commerce, 1977

During the seven decades of the production of mass produced vehicles the automobile has penetrated its U. S. market quite deeply (Fig. 5). On average, an automobile is available to almost everyone with a drivers licence, although there are variations among households correlated with age of household members and income. Low income and/or older households own fewer than average vehicles.

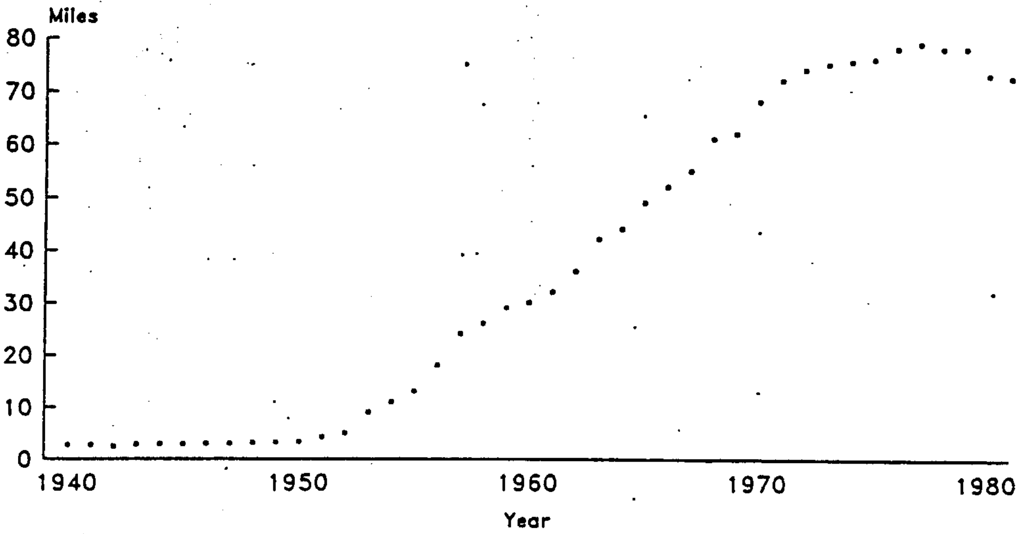

Figure 4: Freeway Miles Per Million Members of the Population of Los Angeles, Orange and Ventura Counties, California, 1940–1981 *

* Data supplied by the Highway Engineering Department of the Automobile Club of Southern California

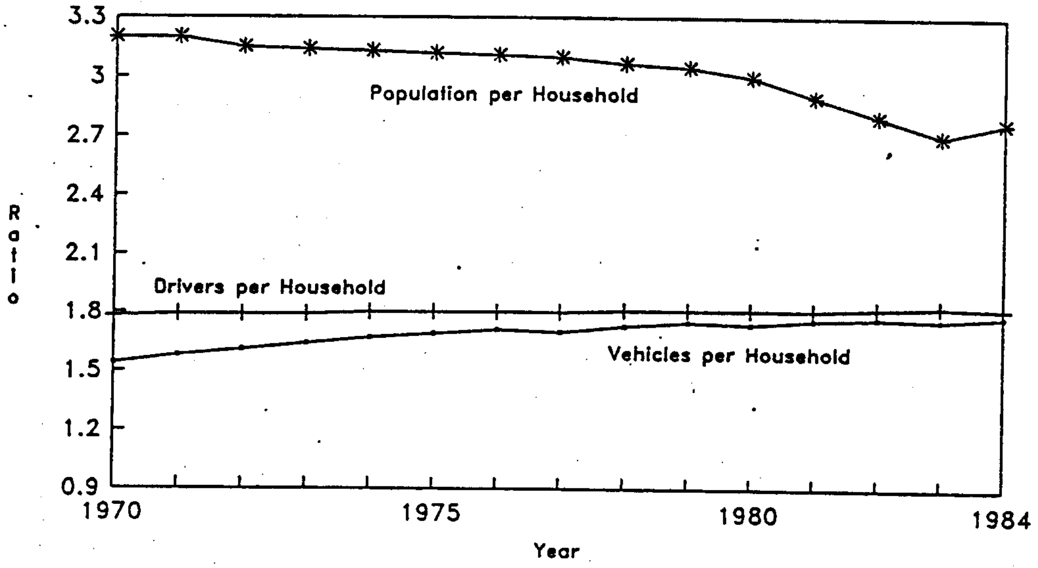

Figure 5: U.S. Population, Drivers and Vehicles Per Household, 1970–1984 *

* Data from U.S. Department of Energy, 1987

The trend in the use of the system is partly suggested by the availability of vehicles. Its also suggested by the average miles per year vehicles are driven. That's now about 11,000 miles in the U.S., having increased gradually from about 8.6 thousand miles in 1936 (U. S. Department of Transportation, 1987). The use of the system is growing mainly because more-and-more persons elect to use the system and not so much because individual vehicles are used more-and-more. The trend in vehicle miles of travel per capita illustrates how use is tending to saturation (Fig. 6).

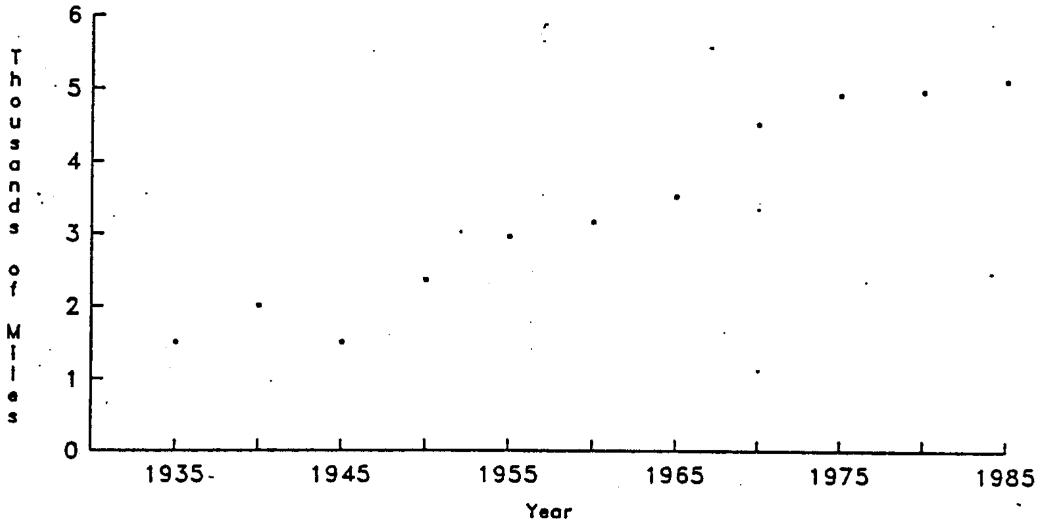

Figure 6: Passenger Vehicle Annual Miles of Travel Per Capita, 1936–1980, Charted at Five Year Intervals *

* Miles of travel data from U.S. Department of Transportation, 1987

Market saturation is one characteristic of mature products. Other characteristics include decreasing returns from new technologies and decreased performance. The discussion will now begin to review these.

The Automobile-Highway Case: Consequences of Technology Development. The life cycle-tied pattern of technology development has been treated. William Abernathy's study of automobile manufacturing adds another dimension to the general pattern (Abernathy, 1976; see also Sahal, 1981). He pointed out that innovations are embodied in products early-on and in processes-of-production as products are standardized. He noted that major automobile hardware developments occurred prior to 1940, and although process-of-production developments began with the transfer line in 1910, they accelerated later than hardware developments and continued longer, indeed, to today.

An examination of the road part of the system shows the same pattern. In road building, the first problem was to get the product right (materials, construction techniques, etc) and, then, standardize it (Seely, 1984). That effort gave sharp returns into the 1920's and 30's, when freeway designs emerged (Gifford, 1985). Beginning in the 1920s, processes tied to scale of production must have become an important source of improvements. Clearly, the production process was refined (Johnson, 1978; U. S. Department of Transportation, 1977).

Ideally, we would like to be able to tie life cycle technology development to the performance of the automobile-highway system. Costs and quality are critical performance measures. Is the real cost of the service decreasing; is the quality improving; or is there some favorable mix of these? Productivity trends provide related measures. Is a given quantity of output being produced using reduced inputs or is output increasing from a given level of inputs.

A number of studies of productivity trends are available (Hooper, 1987), but, with the exception cited below, these do not match the system structure as discussed in this manuscript. Also, by focusing on inputs and outputs, productivity studies take a "black box" view of changes within activities. To better connect modal performance to stage in life cycle, systems, and technology, data will be used that show trends that can be tied to technology.

The California Department of Transportation has calculated a highway construction price index (CHCPI) beginning in 1946, and that index is compared to the consumer price index (CPI) in Figure 7. Briefly, construction costs lagged the CPI until the middle 1970s, and it has escalated above the CPI since. A study of construction productivity trends for U.S. Federal-aid highways found total factor productivity increasing until about 1965 and decreasing subsequently (Kane, 1978).

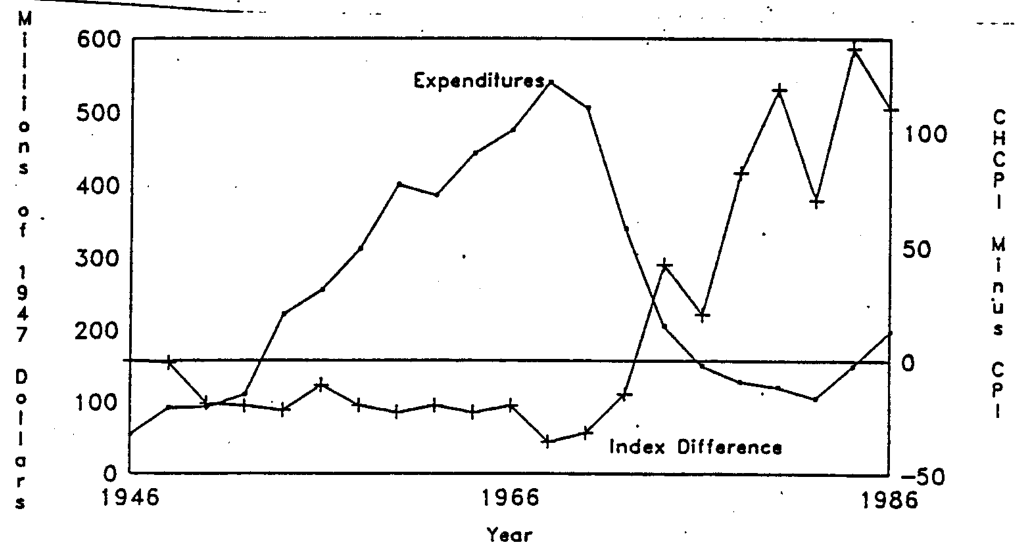

Figure 7: California Highway Expenditures in 1947 Dollars and the Difference Between the California Highway Construction Price Index (CHCPI, 1947 = 100) and the Consumer Price Index (CPI, 1947 = 100), 1946 to 1986 *

The productivity and cost trends can be tied to technology, at least in a rough way. Moavenzadeh refers to playing-out of mechanization and management advances initiated the 1920s (Moavenzadeh, 1985). He also refers to highway construction progran expansion and the achievement of scale economies. Other sources highlight similar trends (Public Works Historical Society, 1986; Johnson, 1978). With the build-up of post World War programs, improvements flowed from scale effects. After the early 1970s when the pace of construction began to founder, scale-based improvements began to be lost.

The situation in automobile production is shown in Figure 8. The factory sales value series shows sharp decreases in the real cost of the product until about 1930, reflecting product and process-of-production technology improvements during the first two decades of the life of the automobile product. The 1930-1950 period was one in which the product was redefined by technology initiatives and pulled by market response. (The former are discussed by Moritz and Seaman, 1981). In a sense, the 1910-1930 product was largely a Ford Model-T derivative, and today's product is derivative of a product revision during the 1930s. During the 30's, the engine and passenger compartments were moved forward relative to the axles, and modern brakes, automatic transmissions, suspension, radios and heaters, and metal bodies began to characterize the standardized product.

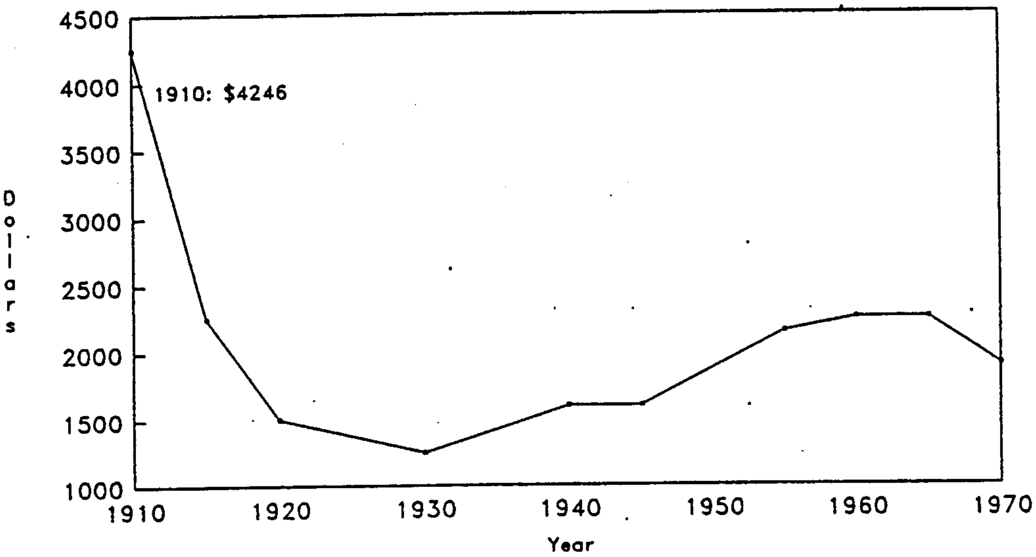

Figure 8: Average U.S. Factory Sales Value of Domestic Passenger Vehicles in Constant 1967 Dollars: 1910–1970 *

* Data from Motor Vehicle Manufacturer's Association

Consumer expenditures data are available for the post World War II period, and these suggest a mild continuation of the more-car-per-car trend (Motor Vehicle Manufacturers Association, 1987).

Nakicenovic points out that the substitution of the automobile for horse drawn vehicles was virtually complete by 1930, and he refers to the post 1930 period as one of the diffusion of individual transportation. He then analyzes the diffusion of quality improving technologies, such as disk brakes (Nakicenovic, 1986). Without rejecting the importance of quality improving technologies, we think of the post 1930 period as one in which development was pulled by the innovation of new, rather that substitute, uses for the automobile. The important innovations were in the use/operations part of the system as the population began to do things not practicable using horse drawn vehicles. Physical realizations of new uses were the auto suburbs and shopping centers dating from the 1920s. New uses and improved vehicles pushed developments in the road part of the system (Gifford, 1984).

With respect to the costs of system use, real costs of vehicle operations have remained stable since 1950 (Fig. 9). Isolated data points for earlier decades suggest sharp decreases in costs earlier in the product life cycle (Ogilby, 1924; National Automobile Chamber of Commerce, 1921).

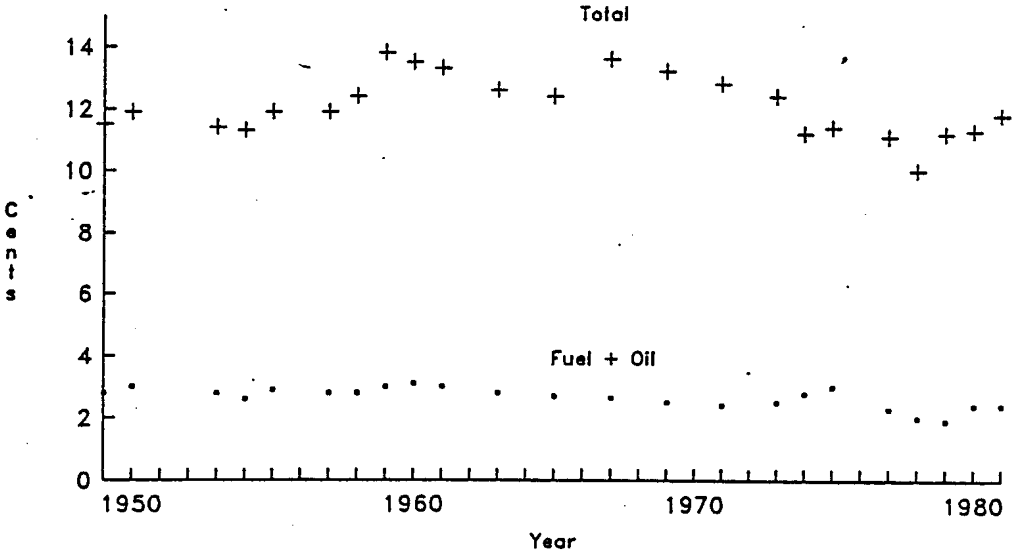

Figure 9: U.S. Passenger Automobile Operating Costs, 1949–1981, in Constant 1967 Cents Per Mile *

* Data from the Motor Vehicle Manufacturers Association

The Automobile-Highway Case: Critique. The purpose of the discussion above was to position the automobile-highway system in its life cycle and to inquire about the past and present contributions of technology to product improvements. The summary statement is that technology made consequential contributions in the past, especially in lowering real costs (1910-1930) and/or improving quality (beginning in the 1930s) but, in comparison, it is not doing much now.

That statement can be disputed in two ways. The analytics are not crisp. The uses of index numbers and comparison of products to the CPI beg considerations beyond those made; the comparison of technology introduction with product costs was a general one. In addition, quality improvements in products have not been fully considered. In particular, both the automobile and the highway have improved in quality during recent decades, though both were building on freeway and automobile designs introduced in the 1930s.

Even so, the broad conclusion certainly holds.

The Air Transportation Case. To present the air transportation situation in a brief fashion, Figure 10 displays the trend in carriers' expenses per domestic revenue passenger mile.

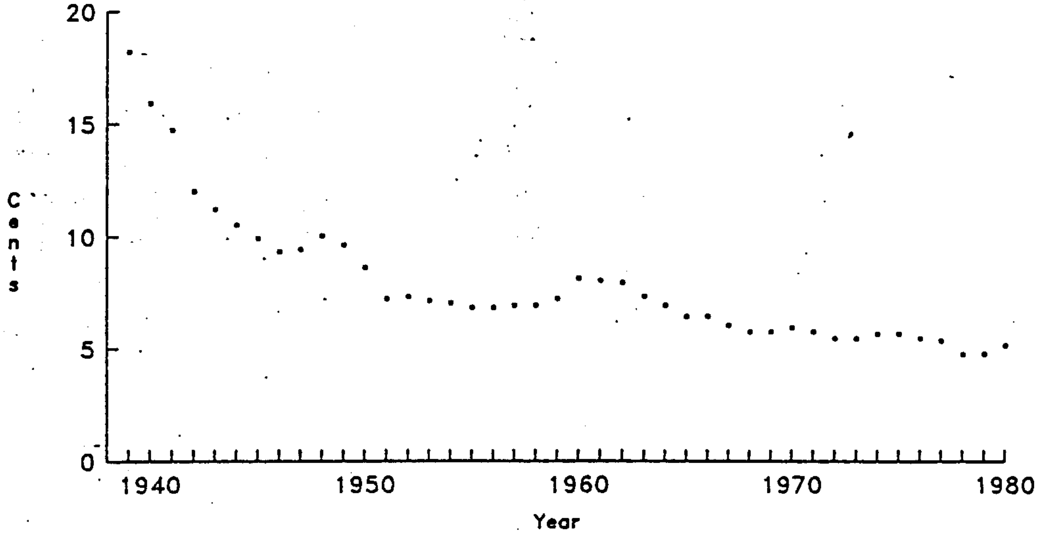

Figure 10: Total Expense Per Revenue Passenger Mile of U.S. Domestic Air Carriers, 1938–1980, in Constant 1967 Cents *

* Data from U.S. Department of Commerce and the Federal Aviation Agency

The introduction of DC-3 type aircraft and subsequent improvement and scale-up of that technology yielded a (reverse) J-shaped trend from the beginnings of the commercial system in the 1930s to the 1960s. Equipment improvements interacted with technology improvements in operations, air traffic control, airport, navigation, and other parts of the system design that emerged in the 1930s.

The introduction of jet aircraft in the late 1950s occasioned a brief period of higher costs, but the cost trend has continued more-or-less along the J-shaped trend initiated in the 1930s. The introduction of jet aircraft did sharply improve the quality of the product. Flight stage lengths were increased, velocity increased, and high altitude, smoother flight was obtained. Safety has steadily improved.

The introduction of jet aircraft also occasioned a partial system redesign process. Airports were enlarged, air traffic and navigation protocols were changed, and firms adjusted operations. Today, there is a search for technologies to flesh out these changes, reduce energy use, and grasp scale economies. Industry deregulation has accelerated that search, and the advantages claimed for deregulation are mainly a result of that acceleration. Aircraft designs, for example, are scaled and tailored to market niches. Hub and spoke airport and operations designs strive to accommodate scale economies from high volume passenger throughputs in airports and along routes (Morrison and Winston, 1986).

In spite of its relative youth and rapid market expansion, the air transportation system has the ear marks of a maturing system, and the chief roles for technology are tailoring standardized products to market niches, reacting to increased factor prices, and supporting obtaining scale economies.

Situation in Other Modes. Brief statements will now be made about other modes.

The container ship system design is well established. Technologies for larger ships, container carriers, and cranes support achieving scale economies. Market niche oriented technologies are sought, especially on the landside of the container shipment.

Tankships and other bulk ships have been specialized to markets and to scale. Technology developments have supported those developments.

In the U.S., current barge, tugboat, lock, and operations technologies emerged on the inland waterways beginning in the 1930s, although features of the system design date from Ohio River coal tows and wicket dams of the middle 1800s. Market growth has been slow in recent years. Technology activities are those characteristic of mature industries.

Mass transit is a mature system. Technologies are being applied to improve product quality and tailor service to markets. In the U.S., private sector operations are promoted for increased market orientation and efficiency. There are markets with decreasing ridership, and adjusting the technology to decreasing scale begs technology development. The construction of street car (light rail) lines is asking whether a mature technology can be re-applied if conditions change.

Shifts in quantities of commodity flows and market locations press for pipeline technologies appropriate for diverse scales.

The U.S. railroads (and pipelines) differ form the other modes in that fixed facilities, equipment, and operations are under corporate control. Although technology mainly finds markets in system parts, there is some opportunity to jointly tailor system parts to market niches. The development of unit trains, using routes and operations specially developed for them, is an example of technologies providing for the tailoring of system products to markets.

The truck-highway system is introducing technologies to capture scale economies, resulting in larger trucks and stronger pavements and structures. More-and-more, trucks are specialized to markets/commodities.

The influence of rapidly improving technologies may be found in each of the modes. Pipelines, for example, have adopted sensor, computer network flow analysis and control, and materials developments. A major thrust in railroad operations is the introduction of new technology control systems, as mentioned. Information systems enable improved passenger and commodity flow control in all the modes.

Opportunities

This previous section began with a list of current technology developments produced by a National Research Council study. It then explored a question posed by that list: What are these developments contributing to transportation improvements? It goes without saying that the technologies are making contributions, otherwise they would not be developed. Technologies are improving safety and reliability, providing for product differentiation among markets, lowering costs or holding back cost increases driven by higher factor prices, and improving service quality generally.

That there are improvements is not the issue; the issue is compared to what and whether pathways for major system improvements are being opened.

To provide for comparisons, products were positioned in their life cycles and fragmentary data on technology contributions to product improvements over product life cycles were examined. Conclusions are straightforward: 1) The opportunity for consequential improvements is created when technologies are embodied in full system designs. 2) Opportunities are captured as the "best," standard or standardized, or predominant technology is created and as technologies enable capturing economies of scale. 3) Once the product is mature and standardized, technology based improvements are real, but small compared to the previous contributions to improvements.

Today's transportation systems are mature. Developments consistent with maturity are one option for the future. Given the high level of "push" from today's technology developments and "pull" by system problems, opportunities are great. Even so, expectations of improvements from technology should be modest compared to improvements obtained in the past.

Consider the automobile, for example. Much is made of current changes in the automobile manufacturing industry. Daniel Jones, one of the principals in the Massachusetts Institute of Technology study of the future of the automobile (Altshuler et al, 1984), concludes that the industry is "dematuring" (Jones, 1986).

In contrast, we interpret the changes as those of an internationalizing mature industry. The industry is coming to terms with the competitive implications of regional differences in factor prices and in the ways hard and soft process-of-production technologies have been honed. It continues the search begun in the 1930s for product quality improvements and the differentiation of a standardized product to market segments.

At any rate, the automobile is one part of a larger system. The standardization of the system puts sharp limits on changes in the automobile; it must fit the system. The issue is system maturity.

New Products to Obsolete the Old:

As a biological concept, the life cycle is accepted as inevitable and irreversible. The long sweep of history does not deny that, for product after product has run the life cycle path. However, history also reports that old products are obsoleted by new ones, and the use of technology to create new services that obsolete the old provides one option for the future.

In the 1800s, railroads and associated feeder roads and waterways obsoleted the waterway-tramway-road system of the 1700s, the container liner system of the 1960s obsoleted a good part of break-of-bulk shipping, and the DC-3 using system of the 1930s obsoleted previous air services.

Considering that the designs of most transportation systems are quite old, many dating from the turn of the century or before, efforts to obsolete old services provide an attractive option. Although modified as time has passed, fundamental features of systems reflect the states of precursor technologies at the time of their births, the nature of markets at the time, and factor prices of the times.

The railroad, for example, was created using a suitable gauge for the times; a few light-weight cars were trained behind head-end power. Seeking mainly scale economies within the given design, today, heavy and high-center-of-gravity cars are incorporated in long trains. The results are difficult train handling and track maintenance problems; heavy, strong equipment is required to handle the compression and tension forces in long, heavy trains. In addition to equipment and way maintenance costs, energy use, damage to shipments, derailments, and car sorting problems follow from the present-day version of an old design.

The electric telegraph was not available when the railroad was innovated, and its adoption by railroads in the middle 1800s did sharply affect organizational structure and management (Chandler and Salsbury, 1965). Today's communications technologies are also sharply affecting railroads. Even so, railroads system designs are little modified.

A close look at most any system reveals the heavy hand of the predominant design and technology as determined by past conditions. Put simply, if the system were to be innovated today, it would be different.

Breaking the Tyranny of the Life Cycle:

Abruptly obsoleteing a system and its product is a disruptive way to circumvent the limitations product maturity imposes on opportunities for technology. It obsoletes investments, institutions, and individuals, as well as products; it may trigger recessions (Santini, 1985). Continuing changes in system designs would yield a more desirable path for change. Continuing changes in designs would avoid the locking-in of standardized technologies for systems and their parts, would track product improvements on markets and changes in resource prices, and would permit full use of technologies, including those that do not fit a locked-in design. Development would be less linear from old designs and more interactive with the environment (Pacey, 1983).

A main factor in locking products into standard ones is the economy of scale achieved from producing a given product. Another factor is economy of scope--by standardizing, systems can operate as networks and achieve efficiencies by integrating operations. Although in the interest of efficiency, network-imposed standardization produces the "one product fits all situations and none well" character of transportation service.

Ayres and Steger propose that emerging computer, robot, and artificial intelligence technologies hold the promise to eliminate the inevitability of the life cycle (Ayres and Steger, 1985). The technologies promise efficient small scale production. Perhaps there is also promise in these technologies for the elimination of networking pressed standardization.

Barriers:

A discussion of barriers is obligatory in an analysis of this type, and with respect to circumventing the constraints imposed by the life cycle, the rule that technological change must be incremental may appear to be an overriding barrier. It is not.

A variety of reasons are given for the incremental rule, running mainly to the point that a technology has to fit into a given situation. That, of course is no more than a comment on the life cycle behavior of systems. The standardization of the product and the technologies producing it define incremental markets for technologies.

Considering incremental change in the broad sweep of transportation history, even those changes that had revolutionary consequences were incremental. Everything incorporated by McLean in the design of container shipping, for example, was incremental. The container was an incremental development from the truck body, the Ideal-X, the first container ship, was a T-2 tankship incrementally changed by adding a spar deck derivative of decks developed for shipping aircraft by sea. The soft technologies for operations and management built incrementally from truck and maritime technologies (Kendall, 1986).

Indeed, in container system development, many of the changes were so slight that, at best, they should be termed minor incremental changes. That is the case elsewhere. The DC-3 itself differed from precursor designs hardly at all. It differed from the Boeing 247 mainly in size, for example. What was different was that a variety of aircraft developments where fused in an aircraft design at the right scale. Then, existing navigation, operations, management, and air traffic control developments came together into a system design.

So the rule that technological change must be incremental does not constrain new system designs. Designs portending consequential improvements may involve some incrementalism or may not. The design is the new technology.

Transportation systems and their institutions are large and complex, yet observations of the development of successful technologies leads to the rule that technologies are developed most successfully by small, independent entrepreneurs (e.g., U. S. Congress, 1980). The image of the innovator in the garage holds. If technology development is to occur, that's how it must begin.

An interacting observation is that systems are so large and complex that single entrepreneurs, or even large firms, cannot do much (National Research Council, 1984). This calls for massive efforts coordinated by governments or some other large powerful organization. The U.S. man-on-the-moon or Defense Department style is called for.

These observations become irrelevant when the pattern of revolutionary change or system innovation by design is noted, but design introduces its own barrier. Design calls for a market niche. The single innovator cannot put the system together in a design in a garage and see if it works from the view points of markets and the technology itself. Stevenson and Pease had the Auckland coal fields of Northeast England for their market niche, McLean had the Texas-New Jersey empty container market niche, Fulton had Albany-New York on the Hudson, and the air system had the American Airlines sleeper-service market niche.

In the face of highly standardized systems and services, the barriers to exploring design options in market niches are very real.

Constraints on imagination are a major barrier. The recent mature or near-mature behaviors of systems provide the experience experts and publics use for thinking about technology; the problems that technology might manage and the things technology might do are judged on recent experiences.

Also, the services provided by existing systems limit ideas on what systems might do. Returning to system design innovations, they occurred in market niches where substitution for existing services provided a competitive opening, but they, and subsequent follow-on developments, explored and found markets for new services. Stevenson and Pease built the Stockton and Darlington to move coal, they were surprised to find that passengers wanted to move too. The early automobile was a substitute for the buggy and a rich man's toy. It took a while to learn how the automobile might be used for more. Matson thought that three containerships moving about 400 containers each would saturate the Pacific market (Stindt, 1983). It took a decade to learn what container shipping could do.

This inability to know markets is the major reason defense style, move step-by-step toward a known goal, technology development is inappropriate for transportation.

We judge the limitations on imagination imposed by recent experience and the need for market niche testing as the critical barriers to major technological improvements in transportation.

Suggestions:

A major suggestion emerges directly from what has just been stated. It is that the innovation and technology development be posed as a system design and trial in market niches activity. An operative word is system, and system design refers to manipulating fixed facility, equipment, and operations. Compared to activities conforming to opportunities provided by the current stages in life cycles of systems, a design in a niche activity holds potential for order of magnitude improvements in systems.

With that guide in mind, this discussion will now turn to suggestions. To align the discussion with current interests, familiar developments will be treated--applications of electronics to highway transportation and the development of small energy efficient passenger vehicles and integral trains. The main objective in making suggestions is not to argue for priority designs; it is to illustrate attributes of promising designs.

Smart Highways; Smart Vehicles. For two decades or so, vehicle manufacturers and traffic engineers have been accelerating the uses of electronic technologies--automating engine controls and improving traffic sensitive traffic lights, for example. Using that experience and rapidly evolving technologies, today, there is interest in combining vehicle navigation, vehicle identification and position sensing, and communication and computer technologies to improve traffic control and traffic flow in congested urban areas (Strobel, 1983). These automated highway system (AHS) developments are responding to technological opportunities and congestion problems.

Also during recent decades, there has been rapid development of automated guided vehicles (AGV) or mobile robots for use in factory or warehouse environments (Warnecke, 1983). The technology is similar to the AHS technology. AGVs utilize optical line following, wire following, or signpost location aids, they communicate with and are controlled by computers.

Although the technologies are similar, there are two important differences between the AHS and AGV developments:

> The AGV is embedded in a system design, it's part of a rearrangement of production processes. The AHS is the adding of electronics to an existing system.
>
> The AHS is oriented to managing a problems--congestion and drivers or truck dispatchers limitations on finding efficient routes. While the AGV does manage problems of material positioning and movement, it's part of a larger effort to explore and grasp opportunities for new modes of production.

The critical difference between the AHS and AGV activities is the AGV activity having greater similarity to past activities that have seeded revolutionary change in transport.

How might the automated highway effort take on more of the system design flair of work with the AGV? The niche available in and in the vicinity of container ports would enable a system design scoped effort. The entering wedges for automation are the efficiencies to be obtained in managing queueing, requirements for timely positioning of containers, and requirements for precise information. Port authorities treat the port area as a design problem, so there is the opportunity to design operations, fixed facilities, and equipment as whole.

Efforts in several ports would provide diverse experiences and seed automation in many areas. The port experience might extend from these seeds into urban goods distribution and management and regional commodity shipments.

Freight Transportation. The railroads in the U.S. are hard pressed by competition from other modes, and more-and-more they are specializing in bulk freight and trailer- or container-on-flat-car movements. For these and other reasons individual railroads and the Association of American Railroads (AAR) sponsor active research, development, and technology implementation programs.

There is also the development of an integral train concept (Association of American Railways, 1984). In the past, locomotives and cars were designed as the market demanded. With concentrated markets for hauling, say, as for coal or containers, the idea has surfaced of designing trains for specific markets, rather than designing locomotives and cars separately. Features discussed for these trains include application of power to axles throughout the train (distributed power), cars permanently coupled, and designs specially tailored to markets--loading and unloading capabilities, for example.

Although design scopes to equipment and operations, its consideration of fixed facilities is limited. There are, of course, track construction and maintenance implications for the routes on which trains might be operated, and some terminal design implications. In most respects, the integral train development is consistent with mature product improvements--it tailors the product to markets.

With full extension to fixed facilities, however, the integral train concept could have a system design character. One system design might involve automated car movements with near constant dispatch and receiving. Building from existing clearances, cars might have a gauge of, say, ten feet and be capable of moving 400 tons, in the case of bulk movements. Absent the necessity to manage the compression and tension forces from car training, requirements for car strength would be reduced compared to conventional cars. On-board diesel-electric power might be used at first (motors and steering on each wheel), with off-board electric power a later possibility. For low value bulk commodities, high throughput could be obtained at low velocity.

Numerous market niches are available. Increasingly, for example, building material aggregates are moved greater distances to urban markets, there are niches in those markets. Coal has been mentioned. Striving for just-in-time logistics in manufacturing and warehousing yields niches.

Reconfiguring the Auto-Truck-Highway System. Building from conditions in the early days of the system, highways accommodate both large trucks and automobiles and neither as satisfactorily as separate automobile and truck systems would. The accommodation of trucks requires low grades, wide lanes, and strong pavements and bridge structures. But even modern highways limit desired truck sizes and weights. The presence of trucks interferes with automobile operations and creates safety problems as 1-ton to 2-ton automobiles mix with 40-ton trucks. Generally, and especially in urban areas, congestion is a problem.

Suppose an urban route was reconfigured to serve only personal vehicles. There is discussion of double-decking urban freeways, and these might be car-only facilities. Absent the conflicts between trucks and automobiles, smaller vehicles become a possibility and lanes might be narrowed. Dealing with the stability problem of small vehicles by leaning and, perhaps, using electronic lane-keeping aids, a 500 pound, high velocity, energy efficient vehicle, such as the Lean Machine developed by General Motors, might become practicable (Fig. 11). Using limited space for parking and reduced lane requirements, the capacity of the roadways might be more than doubled.

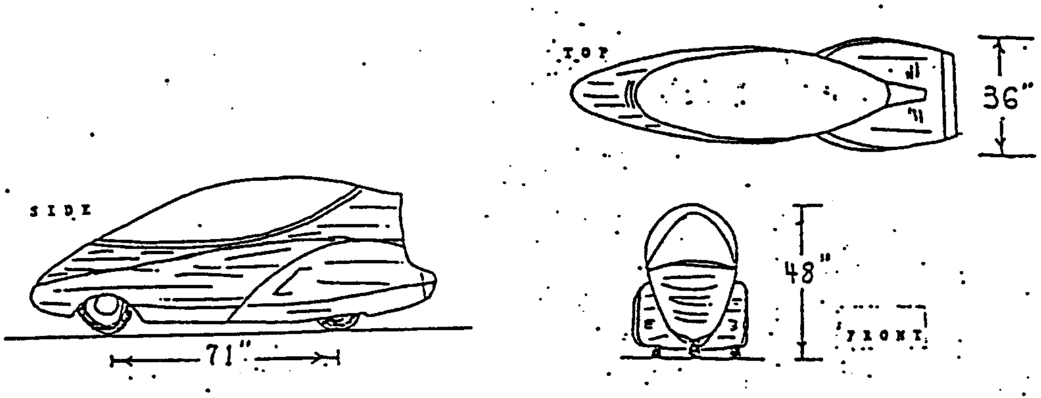

Figure 11. A Possible Commuter Vehicle, the General Motors Lean Machine.

At the same time, truck-only highways might be developed from unused rail right-of-way or carved from existing road spaces. Special interregional routes or facilities in the vicinity of ports or industrial districts might evolve. Such facilities might take on AHS features specialized to them, perhaps, features evolving from AGV systems.

What the Suggestions Say:

Presented only in outline, the suggestions have an grasped-out-of-thin-air character. However, they were selected because they illustrate several attributes that history says are important to major technology advances. In the background provided by previous discussion is this paper, the attributes identify easily.

First, the suggestions are conservative in that they build from existing and emerging technologies. They are also conservative in that they depend, at most, only on incremental improvements of technology.

Second, all of the examples are system design oriented. the first order building blocks are the major parts of systems--fixed facilities, such as guideways and terminals; equipment; and operations. Although not emphasized, technologies that crosscut or fit parts are also building blocks. Although also not emphasized, the designs involve both hard and soft technologies. An automated port, for example, would demand development of appropriate soft operations technologies.

Third, each example was market niche oriented. Each was oriented to a niche, or many similar niches, where the three major or first order parts of the design might be manipulated.

Fourth, each promised efficiency or product quality improvements as a substitute for existing activity. Short term pay-offs could motivate development.

Fifth, each might open options, as opposed to technology developments that strive to use technology to "mine-out" gains from further development of a given, standardized system design.

Further exploration of the suggestion for redesigning the auto-truck-highway system will illustrate important aspects of the fifth point, the open options point.

The passenger vehicle described could be considered a commuter car--an inexpensive, high velocity, reduced energy and space using vehicle for commuting. The idea for a system incorporating that vehicle can be expanded to systems serving a variety of social purposes. A neighborhood car-road system could be imagined in which low velocity, environmentally benign, easy to drive, inexpensive and fuel efficient vehicles serve for school, shopping, and socialization trips.

Extending, systems can be thought of yielding many vehicles for every garage and suitable guideways and modes of operations. Road capacity should not be a barrier, for specialized vehicles would make efficient use of existing space.

There are two points to be made now. One is that a design in a niche would open-up social considerations of options--options that are now hidden because of the lack of stereotypes of what might be done. It is in this sense that a new design "seeds." It is also in this sense that, as a sociotechnical system, transportation innovations are social innovations. Given an idea of what might be, interaction with mar,kets drives design derisions.

The second point is that the design in a niche should be consistent with emerging social and economic trends and with resource situations. In addition to taking advantage of modern manufacturing methods and materials, a commuter car could be very energy efficient and, relative to existing vehicles, benign with respect to noise and air pollution. Shortages of well-positioned urban land would be eased with a high velocity, low congestion-creating and space using vehicle.

The inexpensive neighborhood system would be consistent with the aging of populations and demands for widened mobility for persons regardless of driving skills or monetary resources.

Increased specialization in all things is one deep running social trend--jobs, recreation, and education (Moore, 1963). The birthing of specialized systems is consistent with that trend.

Proposals for small cars are not new, and there have been efforts to market them. The present proposal is different, for it is a system proposal, a design involving guideways, vehicles, and operations.

Closure

This discussion began with an examination of the transportation product life cycle. The examination of the windows for technology available as a product moves along its life cycle and the improvements induced by those technologies revealed that:

1. System innovations require only off-the-shelf technologies, although they may involve some development; their key features are the system scope of the designs and the testing of designs in market niches. They seed major opportunities for technology-induced improvements.

2. Once the system is innovated, there are major opportunities for technology to improve system parts, the processes-of-producing those parts, and the services provided. As products become standardized, there are opportunities to develop technologies to support achieving economies of scale and scope. These technologies permit achieving factor or two or more decreases in costs and/or improvements in product quality.

3. As a system begins to saturate its market, standardize its product, and mine-out scale and scope and other sources of efficiencies, the market for technologies becomes more and more limited. However, increases in the availability of technologies, as is occurring rapidly today, and the escalation of problems as mature systems attempt to react to changed conditions, opens opportunities for cost effective activities. In a sense, the window for opportunities keeps getting smaller as the pressure to use technology gets greater.

With this pattern in mind, the discussion turned to suggestions for improving the applications of technology to transportation. Suggestions or examples of applications were given. These emphasized testing system designs in market niches, especially designs that might seed new developments.

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