Title

Transportation Opportunities and Constraints: The Performance of Urban Highway Transportation

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Transportation Opportunities and Constraints: The Performance of Urban Highway Transportation

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This report is the first in a series. The objective of the series is the definition of opportunities for shafp improvements in highway system performance, say, improvements on the order of two or more. Toward that objective, this first report considers system performance as such and the status of the economic and social services enabled by the system.[1]

The report presents a first-pass analysis. Revisions are intended as the work continues.

The Problem:

Public works, transportation systems, and, in particular, highways have a grand record of improvements. Over the decades, the real cost of providing facilities has decreased, and there have been steady improvements in the quality of the products or services provided.

The situtation today is different; costs are not decreasing, service is not improving., Today's imperative is more than managing cost increases and service deteoriation. It is to recapture the steady improvements known in the past. To do that, the answers to two broad questions are needed.

> What tools promise improvements today and in the future? Because improvements in the past have been great, tools are needed that will yield sharp improvements if the service improvements of the past are to continue into the future.
>
> To what problems and opportunities should those tools be addressed?

These questions are not independent of course, for tools must be judged on their responsiveness to problems and opportunities.

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1. A portion of the text incorporated in this report was used in the author's "Transportation Technology: Yesterday's Accomplishments; Today's Opportunities," and presented at the New Zealand Roading Symposium, August, 1987.

An examination of today's debates revels that there is a problem and gives no hints of opportunities. Strong social consensus on highway development opportunities or needs is absent: naysayers counter every proposal; some publics insist that every project be decorated like a Christmas tree with gifts for all. Capital is short, it is claimed by many deserving programs, and there simply isn't enough for all.

Some say that the task has changed; opportunities comparable to those in the past are no longer recognized. It is said that highways are largely deployed, and the problems now are to manage and repair; today's effort must be redirected to these new tasks. Managing and repairing are labor-intensive, and productivity improvements come hard. No one can debate the appropriate preservation of the (about) two trillion dollar highway investment. Investment in preservation is not, however, capturing opportunities of magnitudes similar to those known in the past. It will not meet the needs represented by new demands on the highway system.

Response to the Problem:

The analysis in this report is unlike conventional responses to the present situation. As mentioned, responses take today's situation a5 a given and ask mainly for better management, innovative funding, and sharpened maintenance or traffic operation5 tools. Without denying the appropriateness of those responses, the responses may be characterized as efforts to preserve and mine-out the accessibility provided by yesterday's highway programs.

In contrast, this present report concentrate5 on the reasons for the present situation, it5 social and economic consequences, and the steps that might yield consequential highway improvements. As stated before, we seek improvements comparable to those of the past, say, improvements of a factor of two or more.

To uncover the reasons for the present situation, the first part of the report examines the highway as a product, and it compares the highway experience with product production experiences generally. The key concept used is that of product life cycle.

A point made in the first part of the discussion is the point of departure for the second part of the discussion, namely: it is inappropriate to think of the highway product as capacity, volume of traffic served, or lane miles. The provision of access, a more general product description, also falls short of describing the social and economic results of the provision of highway facilities.

Striving for a way to capture the social and economic work enabled by the highway product, and to identify the status of the services provided by highways, the second part of this discussion uses congestion as its title. As will be seen, the term is used in a broad way. The focus is on off-system consequences of highway development.

THE HIGHWAY PRODUCT

Having deployed a magnificent road system, and nearly completed the interstate, the federal, state, and local highway community lacks a social imperative to undertake new tasks of the importance of those of the past. Lacking consensus about an imperative, maintenance and repair emerge as priorities by default. Yesterday's imperative to provide ever increasing access has shifted to preserving what has been achieved.

Put in product language, decades ago society clamored to purchase a new product. That purchase has largely been completed.

Indicators of yesterday's provision of access display the situation crisply. The modern era of highway transportation required that roads be paved and otherwise made suited for motorized vehicles. That task began about 1910, it was taperinq sharply by the 1950s, and it had essentially been achieved by about 1970 when the inventory peaked-out at about 80 feet of paved road per capita (Figure 1). Today's larger populations of vehicles and persons are accommodated on a system that was essentially market saturated about two decades ago.

Individuals' use of the access provided by the road system grew as facilities were provided. That use) as indicated by the availability of automobiles to households and drivers, is near saturation. The number of vehicles held by the average household has been catching-up with the number of drivers per household (Figure 2)--a trend that extended pass 1970. As the population grows and as the cohorts of older households containing persons who never learned to drive disappear, demand is increasing. Consequently, congestion is seen by many a5 the number one highway problem.

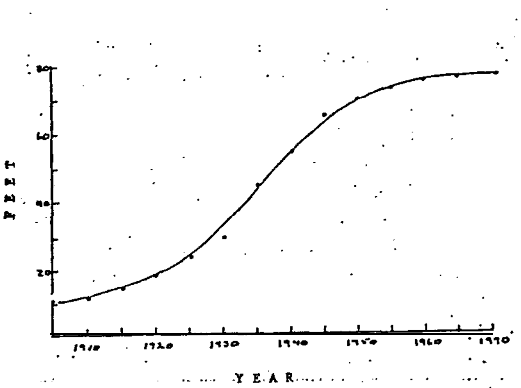

Figure 1. Linear Feet of Paved Road per Capita 1905-1970

Calculated from data in the U. S. Bureau of the Census, Historical Statistics of the United States, 1776 - 1976.

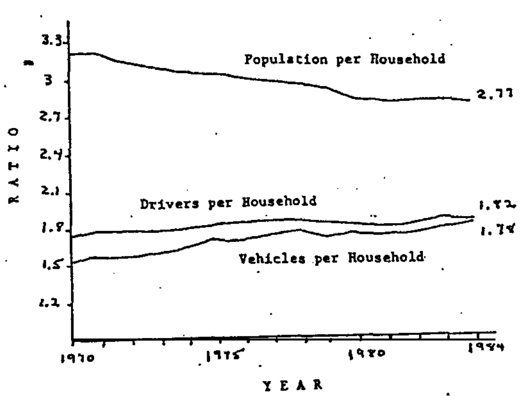

Figure 2. Population, Drivers, and Vehicles per Household, 1970-1984

Source: Oak Ridge National Laboratory, Transportation Energy Data Book, No. 9, 1987.

In product language as used in the private sector, the highway is a mature product. Indeed, actors in the highway community comment on maturity. The notion that the system is largely built-out or in-place is the basis from which today's tasks are prescribed as efficient preservation and improvements here and there of the existing system. Those tasks have replaced yesterday's construction task.

Product Life Cycle:

Maturity is a stage in a product's life cycle, and the discussion will now examine the private sector's use of the life cycle notion for product management and planning. The highway product differs in important respects from a private sector product, and those differences will be noted.

Maturity boding senescence is a stage in the biological life cycle. Applying that cycle to products (or services), a product is first conceived as idea and birthed as a prototype. Through childhood and adolescence the diversity of designs is reduced, and at maturity the product is standardized, and change is slow and evolutionary. The market is saturated as market penetration moves along a S-shaped curve such as that in Figure 1. At that point, the producer's task is to remain competitive by minimizing costs. Emphasis is on reducing input factor prices, such as raw material costs, and on more efficient process-of-production technologies, achieved by substituting capital for labor where ever possible.

As mentioned, producing a well-defined product at less cost is today's view of the highway manager's task. (In this text the term highway manager refers to professionals generally.) Emphasis is on improved materials and designs to lower costs, and emphasis is also on better management of production, say, using pavement management schemes. The Strategic Highway Research Program in the U.S. mainly has improved asphalt materials and lower maintenance costs as its objectives, for example (1).

The idea of product life cycle is central to strategic planning in the private sector. As taught in business schools, one of the manager's tasks is to ride a product cycle in profitable ways. Aware of the S-shaped market penetration curve and anticipating maturity, the manager's second task is to make timely investments in research and development to find new products to replace the old.

Experiences give managers understanding of product cycles. In many cases, cycles are short and within the memory of individual managers. Disk memory drives and electronic digital watches, for example, were each birthed in 1975 and were mature products in about three years (2). In cases, cycles may not have been recent, but are well preserved in institutional memories. Beginning about 1910, the Model-T Ford ran from birth to death in about sixteen years. Although the Model-T cycle was not experienced by today's managers of automobile manufacturing, it is part of institutional memory or lore, and managers use lessons from the cycle.

The product life cycle tells managers how they must behave if they are to be competitive. Managers gear process-of-production technology to the stage in life cycle, and as a product moves toward maturity and senescence, process technology is finely honed to lower costs. ' The lower costs achieved are thought of as resulting from moving along a learning curve, and forecasts of production costs and market growth guide capacity investment considerations (3). Off-shore production may be sought by managers in high production cost nations to lower the costs of producing aging, well defined products.

Textbook theory and practice differ, of course. Rather than a continuing process, strategic planning is often given priority only in response to crises triggered by aging products. Crisis questions addressed include: Should manufacturing rights be sold to capture residualprofit from a dying endeavor? If a product holds its market in spite of its age, should it be used as a "cash cow" to fund new endeavors? Should the firm make quick investments in research and development to hasten the obsolescence of old products by finding new ones to replace those becoming less profitable? As an alternative to investing in research and development, the question often is, Should the firm purchase *more* viable firms and their products? How should a high cost producer of a mature product react to low cost off-shore producers?

Using the Life Cycle Concept:

The product life cycle concept and the questions it poses for managers unfold neatly. The lessons are simple in outline: 1. understand the life cycle of the product, 2. manage current products in light of it, and 3. seek new products to replace old, maturing products. What do these lessons say to highway managers?

Although the lessons are simple, their applications do not always run smoothly. As just mentioned, private sector managers often react to life cycle crises rather than use the cycle concept through the entire life of a product. Managers often fail to be technologically aggressive. A recent study of top production managers points out that most have been trained in business schools and self-identify as strategic planners (in contrast to the product and marketing and, then, finance and legal managers of earlier days). All express a strong belief in the power of technology, but do not give it top priority.

Instead of early investment in technology development to create new products to replace the aging, managers accept the life cycle as inevitable (4). Perhaps these observations say that lessons from the private sector are similar to the parent's admonition to the child, "Do what I say, not what I do."

In several ways, the situation in highway management is the inverse of that in the private sector. Although the term maturity is sometimes used, the life cycle notion is far from being an every-day highway management concept. Also in contrast to private sector managers, highway managers know technology and routinely give it top priority for problem management. At least that has been true historically.' Today, highway managers often give better management top priority. *At* any rate, taking action using technology tools is far from a lost art in the highway community as it seems to be in many parts of the private sector.

Because the highway product has not been thought about in life cycle terms, this discussion now turns to examining the highway cycle before identifying other ways in which the highway manager's situation differs.

Although the highway system has ancient roots and some are evident today in route locations, today's highway system was birthed with recognition that good roads were necessary to commercial agriculture. That occurred in the late 1800s in the U.S., and first was marked by the development of state road programs in New Jersey and Massachusetts and the *Office* of Road Inquiry in the U.S. Department of Agriculture. (The Office of Road Inquiry evolved through the Bureau of Public Roads to today's-Federal Highway Administration (FHWA).)

Market acceptance of automobiles and trucks then fueled and steered development. Road use by autos and trucks mandated improved road surfaces, geometries for higher velocities, and larger and stronger bridge structures. Aided by road tests, diverse designs were standardized. As was the case for the Model-T automobile, process-of-production technologies were developed that yielded ever-decreasing costs.

Also like the fate of the Ford Model-T, newer products replaced the old. Rounds of new-road products appeared in the U.S. in the 1920s and 1930s. At first, these new designs responded to the failure of designs adopted in the 1910s, especially pavement designs. Later designs responded to the needs of traffic growth and increasing vehicle weights, sizes, and velocities. Designs developed in the late 1930s formed the basis for the interstate highway system, the system that preoccupied U.S. highway engineers from the late 1950s and until recently (5). From an overall view, these new designs or new products fitted into the life cycle indicated by Figure 1. Similar S-shaped curves describe how new designs of automobile vehicles fit an overall S-shaped curve (6,7).

Critics who say the public highway system would gain much from the emulation of the private sector should be aware that the highway community has a remarkable record of replacing old products with new. Such a record is not so common in the private sector, where producers of old products too often fail to displace those products. Old firms wither and often die. New products are created by new firms.

An additional way in which the highway manager's situation differs from the private sector manager's may now be identified. The private sector manager lives with the threat of new products produced by competitors. That's hardly the case for highways, for they occupy the turf. If improved or new highway products are to be produced, they will resul't from the actions of highway managers rather from the actions of competitors.

The importance of that difference can not be overstated, for it places an enormous social responsibility on the highway manager. Private sector managers' failures do not impede social progress, for competitors will assure progress. In the absence of competition, highway managers' failures may thwart social and economic progress.

The final way in which the highway manager's situation differs stems from the nature of the product. The highway product is more than just a highway. First there is the facility yielding the penultimate product of mobility or accessibility. And its not just the highway that yields accessibility. The highway in consort with the vehicles usinq the highway and the skills of users provide accessibility. This multiple component system (fixed facilities, vehicles, and operations) ultimately provides for the specialization of economic and social life, choices among work and consumption options, and for more.

Considering the relation of the highway to the larger system, the highway manager's job is immensely more difficult than the private manager's job. The key factor is the way the hiqhway product must work with other system components, i.e., vehicle and use components. At first glance, that may not seem distinctive to highways, for the requirement to fit to other things is common to many private sector products: a disk drive has no value unless connected into a computer system; a video tape is worthless without a system that will play it.

The difference is seen when system management is considered. There are private sector actors that manage systems. Managers assemble otherwise worthless products into automobiles, computer systems, and myriad other end-products. Those managers explore markets, take risks, and may reap rewards. They recognize when a new component part may be incorporated into a system to greatly improve it, as managers' at Sony did when they built new product5 on transistor technologies.

Al though there are highway managers, vehicle producers, traffic engineers to manage operations, and numerous other important actors in the highway system, there are no system managers. There is no one to ask if the components are properly assemb led. Components are assembled using incremental rules. Each component actor is concerned about markets and plans in light of them, but no one asks about markets for components working as a system. If a new technological option comes along, no one asks how it might fit the system, the new product is considered at the component level where it may have no use or very limited use.

A Recent Development:

Underlying the private sector manager's use of the life cycle concept is the assumption that is as irreversible and inevitable as its biological model. Once birthed, a product moves inevitably through standardization to technological and market maturity. The product life cycle is locked-in by process-of-production technologies.

Process-of-production technologies lock-in managers' options this way: Lower cost is the key to market success and profits. That's achieved in the production process by substituting machines for labor everywhere practicable, and by achieving economy of scale in production. That locks the manager in because any change that might reduce economy of scale escalates costs. Change would also require recapitalization of machinery. For these reasons, change is risky in the extreme. If unsuccessful, it can be disastrous, as the Chrysler Corporation found in the 1930s when it introduces a radically streamlined line of automobiles.

Aware of the rapid growth of new technologies, imaginative private sector managers' are asking whether those technologies might provide for change in process-of-production technologies, change so radical that products can be changed without incurring massive risks (8). Robotics, computer aided design and drafting (CADD), and computer aided manufacturing (CAM) are the technologies under assessment in the private sector. Imaginative mangers think of the factory of the future as one that can efficiently produce end less variations of products for diverse markets. Production could track products on changes in markets, and, most importantly, continually revise those products so that they do not become mature.

Highway managers have changed process-of-production technologies as tools have become available. The soft technologies of CADD, information systems, and project management using computers (a relative of CAM) have been adapted and adopted rapidly. Combined hard and soft technologies, such those realized in robots, increasingly have their counterpart in machinery. The railroads, in particular, have recently pressed machinery development, but other modes have progressed rapidly too.

Similar to the potential for the private sector, rapid improvements in process-of-production technologies hold potential for continuing change in the highway product.

To summarize this discussion of lessons for managing the product life cycle, they are simple when stated in broad terms: understand the cycle and manage accordingly. However, the highway manager's situation is not so simple.

On the downside of the highway manager's situation, the highway manager is one player in a system of highways, vehicles, and users. There is no system manager who might imagine and design new system products. In addition, competition is not a threat to the highway product.' That seeming blessing, when compared to the private sector manager'5 situation, places a heavy social responsibility on the hiqhway manager. Highway management has the responsibility to obsolete its own product, but, as one player in a system, has only partial control of the provision of accessibility and providing for the social and economic returns from improved accessibility.

On the upside, the highway manager is knowledgeable of one essential tool for improving products, the uses of techno logy. Also, recent developments of process-of-production technologies hold promise for continual product improvements.

Lessons From Transportation History:

The discussion above has examined the highway as a product. It sets the stage for asking the question, How are new products evolved? The broad objective of our study asks that the question be explored for products generally and in the frame of today's highway situation, institutions, and technological tools. However, the full exploration of the new-product question is too large for the present report. Also, some groundwork has not been laid. In particular, the questions of directions of development have been explored.

The limited discussion to follow begins with the observation that the maturity of a transportation system is new only in the sense that it is a 5ituation that has not been experienced recently. Its not new in the sweep of transportation history.

Systems were at or near maturity in England in the early 1800s when canals, tramways, and toll and local roads were pretty well deployed. Their technologies were 5tandardized. There were some broad canals, but most were six foot canals with boats to match. Telford had worked out how to build roads, and the carriages and wagons of the times matched those roads. Tramways were set up with iron wheel carts, iron rails or L-shaped iron plates, and rope haulage was powered by stationary steam engines. On the soft technology side, methods had been worked out for the creation of facility-providing institutions, for financing, and the like. Users had adjusted to the services available, and facilities had pretty much saturated their markets. Their products were mature, or nearly so.

Two tasks were recognized. One was maintenance and better management, a more-for-less task. John MacAdam's classic work on roads is remembered for its contribution to that task, as is Lord Parnell's book of about the same date. Robert Ful ton, among others, contributed to the canal more-for-less task; he designed more efficient locks for small canals. The other task was that of fleshing-out the system --providing the facilities and services that could still be economically offered. That activity can also be thought of as mining-out; it is capturing the remaining accessibility that could be gotten from existing systems.

The former task is very much like the transportation system management (TSM) task given high priority in the U.S. Current additions to the interstate are fulfillinq the latter task--fleshing-out the system.

The problem of the Auckland coal fields in northeast England posed a fleshing-out task, seemingly an impossible one. The coal fields were located at an elevation too high to be economically served by canals, and the bulk carriage of coal in wagons on roads was out of the question. That left a tramway alternative.

In 1821, a promoter, Edward Pease, obtained a act from Parliament for the construction of a tramway, and he engaged George Stephenson as his enq i neer. Pease's dream was marketing Auckland coal on the London market, and the task for Stephenson was careful engineering to keep costs down so that the coal could be competitive in that market. Stephenson sought to do that by careful selection of the 26-mile route between Darlington at the coal fields and the port at Stockton on the River Tees. Route selection was made with an eye to requirements for cuts and fills, and calculations were made to balance cuts and fills. Stephenson provided an efficient combination of near-level grades for horse working and incline plane5 for steeper grades. On those grades, self-acting planes or rope-haulage using stationary steam engines were used, depending on grade steepness. Stephenson achieved more-for-less for the tramway mode through good location analysis and detailed engineering.

Stephenson had some experience building steam locomotives for tramways. I n the interest -of economy -and concerned about uncertainties over the rising price of oats, two locomotives were ordered for use on the near-level sections of the route. At the time, these locomotives were envisioned as no more than fuel efficient horses, each locomotive was to haul a three-ton cart on near-level grades at about 3 mph, just what a horse could do.

In addition to his role in managing financial and political aspects of the tramway's promotion, Pease also strived for more-for-less. To keep unit costs down, he adopted the road and canal traditions of common carriage, anyone with equipment and the urge could use the facility. That had not been the case with tramways earlier, for they typically were provided by mine or quarry owners and served only them.

Pease was especially hard-pressed when Parliament reissued his charter to allow for use of locomotives. Its member, John

Lambton, who marketed coal from Durham in London and wanted to protect his business, demanded and got low rates on coal to be transshipped written into the charter, rates so low as to make the project seemingly impossible and not a threat to Lambton's London coal business.

The rest, as they say, is history. Opened in 1826 the Stockton and Darlington was successful, and it became know as the world's first railroad. It was hardly that, yet promoters building from the Stockton and Ddrlinqton experiences triggered the great expansion of the world's railroads in the 18005.

Lessons:

Although tramways are not highways and the late 1900s are far from the early 1800s, the transformation of the tramway to the railroad says much about achieving more-for-less from mature systems. The experience says how a new product (railroad services;) ran be developed from an old, mature one (tramway services).

The first lesson is that the facilities yielding new products are build from old know-how and experiences. Indeed, Pease and Stephenson triggered radical change without doing anything very radical. They desiqned their facility using huildinq blocks already available in canal, road, and tramway experiences. There were hard technology building blocks from the then transportation experiences, and there were soft building blocks too, such as the idea of the common carrier. The key to product improvement was putting those building blocks together in a new and better way. Using other words, and a play on words, the new was created "by design." There was the design using buildinq blocks, and there was the objective (design) to do better.

The steam locomotive was a newer, but not a new, building block. It had been used on tramways before. However, a new buildinq block is not necessary to product improvement. One example that proves the point is -the Boeing- 247 of the early 1930s, quickly followed by the Douglas Corporation's Model 3 of similar design, but larger. Those_ aircraft triggered the growth of air transportation in their era. Yet they were new only from a design standpoint; everything incorporated in them had been used before. They were successful because old building blocks were combined in a new, more productive way.

This building-from-the-old point counter5 the naysayers argument that nothing can be done because of our large commitment to existing highways. Just the opposite argument holds. Existing highways are a rich resource on which the new might be build, and today's world offers many other resources waiting to be used.

The radical change in the air transportation services associated with the B-247 and the DC-3 underscores the point that existing facilities are resources. Although associated with the aircraft, the services that emerged were also based on precursor developments in air traffic control and navigation, the experiences of firms, airport management and construction skills, and other available building-block resources. The aircraft was built from available building blocks, but radical improvement followed from the way the system blocks came together. The new system design offered radically improved services.

Aircraft similar to the B-247'and the DC-3 were developed in West Europe in the 1930s, but they did not trigger radical change in the absence of other system building blocks.

For a similar example, the development of container liner and related land services involved much more than the development of the container. Ships, ports, liner, truck, and rail firms, and shipbuilders were all involved, and they were resources for system change.

It is unfortunate that many discussions refer to change in systems as if vehicle innovations created change. The process is more widely scoped. In essence, it is a system design process.

A second lesson for highway managers flows from the nature of the Stockton and Darlington. It wasn't a full blown railroad on any measure; it was a horse-cart tramway with a couple of locomotives. It should be viewed as a test-bed where lots of things were tried in a market niche. It asked just how well careful engineering could manage costs, was there a market for passenger service, how should passenger vehicles be designed, and would common carriage work? It was a test-bed on which those questions were explored.

Interestingly, the Stockton and Darlington was not so much a test-bed for locomotive development, although it provided information on locomotive use on a fairly long route. Its main hard technology testing was of use of fish-shaped plates for rail and both stone and wood blocks for rail support.

The Stockton and Darlington gave only first approximations to the answers to the questions it explored. Those approximations were refined as the Liverpool and Manchester, London and Birmingham, Baltimore and Ohio, and other railroads were constructed and operated.

The lesson here is test production formats and explore markets; ask and answer questions as opportunities unfold.

Unfortunately, this lesson is not easily applied in today's world, especially in the public sector. Today's style is to set goals and assure financial folks that those goals can be achieved. Funded projects then march from milestone to milestone without asking any questions for which the answers are not already known. If the Stockton and Darlington had been subjected to today's procedures, it would have failed on the claims that locomotive wheels would slip on rails, that common carriage of freight on tramways was an uncertain matter, and that there wasn't any need for more coal on the London market. Watt had already refined the steam engine to the n^{th} degree, and what could be done with locomotives was well known. At best, Stephenson was an untrained mechanic with little experience and even less reputation. Pease was a Quaker with limited economic motivation.

Looking elsewhere in transportation history, assessments represented by prevailing opinion reached similar conclusions: The automobile was a rich man's folly, there would never enough money to pave the highways the automobile system would need. The future was in larger, faster break-of-bulk ships, container shipping had little future. The jet aircraft would never be built in enough copies to be profitable for the manufacturer, the market wasn't there.

Our final lesson is on the market side. The Stockton and Darlington made new resources available to the economy--coal from the Auckland deposits. It expanded the boundary of the possible. But that particular result pales when the broader impacts of railroads are considered. Elsewhere, they extended the reach for resources vastly, and they enabled doing the unthinkable such as farming the wheat lands of the American West. Broadly, railroads supported new social and economic organizational formats, and the developments based on these.

The Stockton and Darlington also found unexpected markets. passenger service in particular. The demand for passenger service was so unexpected that railroads following on the heels of the Stockton and Darlington continued to be planned for freight service, yet were swamped by passenger demand when opened. Passenger service became the bread and butter of railroads in England and the United States, and that continued for decades.

Generally, the railroads opened opportunities for doing new things in new ways, and opportunities were grasped that could not have been imagined at their beginnings.

That's the market lesson. Successful new services enable society's improving the ways old things are done and doing new things. If the manager offers new services, society will make judgments of their values.

The lessons presented in this section are that new services are built from the previous experiences of service providers. To provide new services, building blocks are arranged in new formats or designs. Both hard and soft technology building blocks are used. The testing of production formats yields information on the working of the technology and markets.

CONGESTION

The discussion of lessons from history was limited in several ways. For one, lessons were drawn without considering the special conditions and opportunities embedded in today's technologies, institutions, and constraints. For another, the markets for new developments were not considered. All that was said was that markets were found by exploring. In the 1800s, exploring was successful because developments were consistent with the social and economic developments of the industrial revolution. What is it that systems might do that is worth doing, what's pulling development?

Leaving the first limitation for a later report, the discussion to follow will concentrate on the second consideration, what might be done that's worth doing.[2]

On-highway Congestion:

Today, as yesterday, congestion on highways is regarded by publics as a major problem, especially congestion on urban freeways. With exceptions, increasing capacity through new construction is not a politically acceptable action. Exceptions include the now yet fully built-up and expanding suburban areas (e.g., Roseville, CA), some suburban built-up areas where the problem is acute and facilities can be expanded without great disruption to adjoining neighborhoods (e.g., Santa Clara County, CA), and areas where massive investments are required to expand facilities and dampen environmental impacts. The Boston central artery replacement is an example of the latter. Its cost is estimated at $3.1 billion.

Given the difficulties and/or limited opportunities for expansion of physical capacity, attention is properly placed on operations improvements on existing facilities. A number of operations improvements are underway, and there is an active search for more effective improvements. There is much promise in computer, sensing, control, and related technologies.

However, as will be seen as this discussion unfolds, off-highway system congestion is a critical problem: i.e., limitations on abilities to do those things the highway system permits doing. Operations improvements to manage on-system congestion should be sensitive to off-system problems.

In presenting this point, the author has two practical problems. For one, it is not an easy point to make. In particular, its hard to make the point that treatment of on-system congestion where it is acute may or may not be supportive of managing off-system problems. The other presentation problem is that we do not wish to denigrate the work of those

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2. The analysis to follow has not been fully polished. It will be revised as work continues.

seeking to devise tools for and implement operations improvements. Absent better understanding of problems and opportunities, their work is proper, and many of the solutions being developed will be appropriate to problems stated in off-system terms.

To deal with these problems in presenting ideas, the discussion will now turn to off-system congestion, returning later to on-system congestion with the perspective provided by off-system considerations.

The Transportation Product:

Transportation's services are usually described as intermediate ones. Transportation provides for the movement of people or goods, it connects or mediates among places and activities.[3] At a more detailed level:

> Transportation makes resources available for use, it offers options for the management of resources.
>
> It enables specialization of production and consumption, yielding choices for producers and consumers and efficiency gains. The individual has many choices of goods for consumption. When serving in a production role, the individual has choices among jobs.
>
> There are also scale advantages to be had. Transportation increases the scales of marketing areas. This permits producers obtaining scale efficiencies and consumers sharing the surplus created by those efficiencies.
>
> Finally, there are agglomeration economies to had. Interdependent activities can be synchronized at places or times.

Highway off-system congestion, as we. think- of it here, refers to how well these off-system roles are performed. Our use of the pejorative word congestion leaps to a conclusion. There are problems with the off-system roles.

On-system congestion arises for one of two reasons. Associating reasons with cases, in one case the user may observe the level of service of a facility slip, say, from level C to level D, and think of that level of service change as the appearance of congestion. In the second case the user may have

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3. There are some problems with that concept: people and goods are transformed as they are moved place to place. A ton of coal in the West can do one thing, at a power plant in the East, it can do another thing. Here, we leave the notion of intermediate activity aside. Its consideration is not necessary to our analysis.

had no change in the level of service, but sense congestion because the desire for service has increased.

On-system congestion seems to arise mainly as described in the first case. In contrast, off-system congestion arises mainly from the second case. Because improvements not taking place are difficult to imagine and because off-system problems may be described in terms other than transportation terms, the off-system congestion has a hidden character.

The outputs described above have positive values, they are good things that transportation does for society.[4] There are also negatively valued outputs such as noise and pollutant emissions.

To balance the identification of transportation products, inputs to transportation should also be noted. Transportation uses resources of many kinds to produce its products. There's the input of drivers and fleet manager's time and skills. Fuel, metals for equipment manufacture, and aggregates for road construction are required. Transportation uses land for routes and for off-route storage of vehicles.

This discussion will not extend to consideration of negative externalities and inputs; a full treatment of off-system congestion should. With respect to inputs, fuel is of special interest as is the use of time.

The discussion turns now to brief considerations of the nature of transportation outputs.

Resources:

Highway transportation, working as a collector-distributor in coordination with other modes, provides cities with access to world-wide resources. In local tributary areas it has provided access to materials such as aggregates and also spaces for recreation and housing. Some of these resources have either been exhausted or are pressed by intensive uses. Today, aggregates are hauled further, there are shortages in sites for garbage and other wastes, and recreational sites are hard pressed to accommodate demands on them.

Of particular interest is the availability of land for housing and other urban activities. Past highway expansion greatly increased the availability of land. Figure 3 illustrates

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4. There is nothing original about this list. Although described in different words, the products identified are mentioned in Adam Smith's chapter on the division of labor. George Stigler's discussion of the division (specialization) of labor builds from Smith's discussion (9). Steigler asked whether the division of labor yielded monopolies; his answer was no. Interestingly, Stigler made no remarks on transportation.

this point very well. As a result of highway construction, the area that could be accessed in thirty minutes from downtown San Diego more than doubled between 1957 and 1970. Available land is in the process of being taken-up by urban uses, and, absent highway improvements, the supply of land is not increasing.

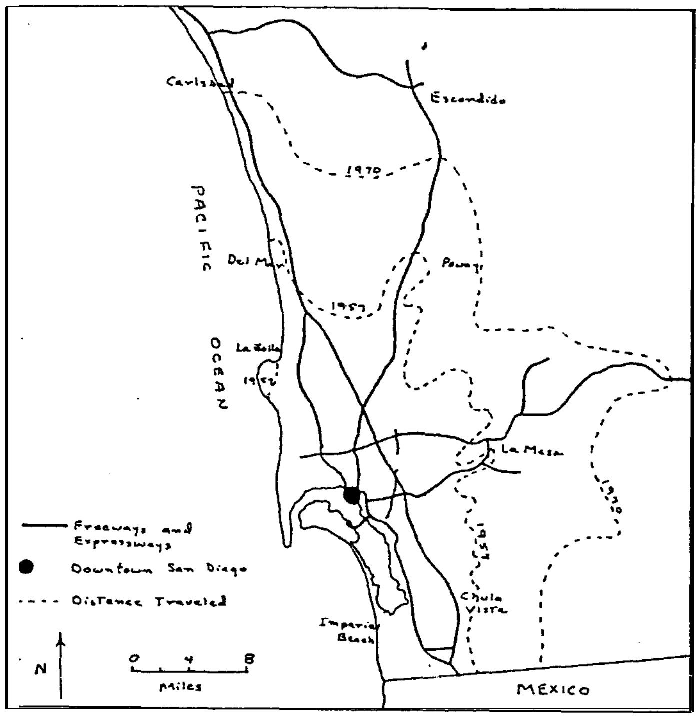

Figure 3: Distance Traveled in Thirty Minutes from Downtown San Diego, CA, during the Peak Travel Period, 1957 and 1970.

San Diego has about 81 freeway miles per million population and only minor congestion during the peak period. Redrawn from maps supplied by the San Diego region Council of Governments.

Specialization:

The dominant social trend has been specialization, identified in particular for jobs (10). The specialization of jobs reflects the specialization of production, and there has also been the extensive specialization on the consumption side. Consumption includes goods and services, and extends to uses of recreational facilities. Highway transportation improvements have enabled specialization accommodating the desires of firms and individuals to capture the efficiencies flowing from specialization.

Opportunities have been pretty much taken up in urban areas for specialized shopping and work facilities, although pressure continues for more specialization. This is especially true in production activities where competition is sharp and increased education level5 and the availability of communications open opportunities.

Scale:

Scale economies are associated with specialization, for the efficient use of specialized individuals and/or production facilities requires markets sized to efficient levels of output. Urban highway facilities enable i'ndividuals to travel to places where specialized work is in demand, and for many persons, travel is to many work sites. Physical products also move on urban faci lities.

Agglomeration Economies:

More and more, product ion involves the careful synchronization of the movement of products amonq plants, raw materials to plants, and products to consumers. As a result, there is emphasis on just-in-time shipment and inventory systems. This same synchronization holds for labor inputs. Specialized labor is called on when needed for efficient production.

Where proximity is required for agglomeration, as in central business districts or outlyinq office complexes, there is very focused demand on urban highways. But in all cases, the demand is for high levels of highway services.

Services Provided for an Activity, Housing:

The pithy statements above do not yield sharp statements about the adequacy of highway services, and very sizable analyses would have to be made to fully judge the status of hi ghway services for the great diversity of off-system purposes. Absent the availability of such analyses, an example, housing, will be used to give a flavor of the processes at work and the status of transportation services.

Four or five decades ago, the typical house was built by a nonspecialized two or three worker crew. The crew would begin with the foundation and end with interior painting. Materials would be brought to site and stored, and then cut and finished as needed. The variety of materials was limited.

Today's organization of housing construction is in sharp contrast. Construction is usually managed by a contractor with multiple jobs underway. Specialized labor is hired as needed, and specialized tools and materials are used by crews. Five to seven labor specialties are typically used. Materials are brought to the site when needed, materials specialized to uses. Much of the material is precut and finished and presorted so that the material needed is readily available, e.g., lumber is stacked so that the next piece needed is on the top of the stack.

The average U.S. builder produces from 5 to 10 houses per year. However, about twenty percent of the new housing market is supplied by 100 builders.

Housing is accessed by local roads, so it has always been dependant on highway transportation. But the high level of dependence of modern housing construction is striking. The specialization of supervision and labor crews and their equipment turns on the access of these producers to enough job sites to warrant the specialization and *its efficiencies. The modern urban highway system enables that access. More than that, it enables access by multiple specialized subcontractors. Manaqers can call on specialized crews as needed and obtain services in competitive situations.

The availability of specialized materials at competitive prices turns on producers access to large markets and the ability to achieve scale in production. Highway transportation plays a role in resulting production and distribution activities. It especially plays a role at the fine detail scale of the local supplier who's ability to stock and deliver as needed depends on access to enough markets to warrant the development of the specialized capability. On the buyer's side, access to several suppliers enables shopping and competitive prices for services and materials.

Off-system Congestion:

The housing example illustrates very well how the services provided by highways, highway products, enable access to resources, scale economies, etc. It also illustrates the concept of off-system congestion. The housing industry is deeply troubled for transportation related reasons.

The housing-production developments described evolved with the surge in housing construction after World War II. Developments emerged in large scale projects, such as the Levittown project on Long Island, and then began to be applied more generally. Advantages to large projects remain, especially site development and management advantages, but they are not as sharp as they were several decades_ ago. Actually, there is some evidence that advantages to large producers have been increasing in recent years, perhaps a result of the problems discussed below.

The developments increased productivity. More house could be constructed for a given sum of money or a given house could be constructed for less money. For some years, however, productivity in housing construction has not been increasing, and it may be decreasing (11). Coupled with lack of productivity gains has been the increases in land and capital costs.

Lack of productivity gains and increases in land and capital costs have escalated the real price of housing. In 1968 the cost of home purchasing was 20 percent of medium income; it was 32 percent in 1985 (12). Lack of productivity gain in new housing construction is of concern3 but it is not the major cause of the increase in real housing costs. Capital costs have sharply increased (13). Land costs have too. The cost of a 10,000 square foot unimproved lot increased 78 percent between 1975 and 1985; an improved lot, 66 percent (14).

Highway transportation developments enab 1 ed the efficient organization of housinq production; it made land available. Today's highway developments are no longer playing those roles. Highway transportation is not supporting improvements. Our term off-system congestion is intended to catch that f ai lure to support improvements. (We do not blame hiqher capital costs on hiqhway product failures, but there is a connection. Bidding for scarce land drives up the cost of capital.)

Lessons; Highways and Housing:

As mentioned, on system congestion is mainly recognized in deteriorations in -levels of service, stressful travel, and variable travel times. The post World War II round of freeway building in California cities got ahead of the growth of traffic for only about a decade (Figure 4), and the situation has been deter iorating for about two decades. Users recognize the presence of congestion, and complain. Because congestion delay is a sharply increasing funct ion of volume, the amount of recognized congestion has escalated sharply and will continue to escalate.

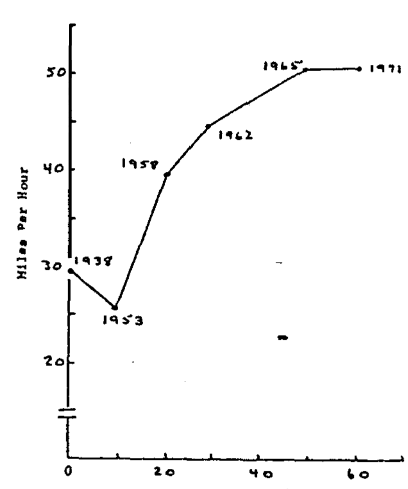

Figure 4. Offpeak Average Radial Driving Speed and Miles of Freeway Per Million Population in Los Angeles-Long Beach, CA, Various Years, 1939-1971.

In 1983 there were about 56 miles of freeway per million population (compare Figure 2). Redrawn from K. P. Pirzadeh, "A Comparison of the Los Angeles Freeway System to Other Major Metropolitan Area Freeway Systems," Automobile Club of Southern California, 1983.

The California Department of Transportation estimates that congestion cost Californians about $2 million per day. (That sum seems low, we do not know how it is calculated.) On a per capita basis, that's about 7 cents per person per day which is nil compared to expenditures on auto travel of about $7 per day. Congestion occurs on specific routes and affects a relatively small number of all drivers. So for some drivers the cost is not nil.

How do off-system conqestidn costs compare to on system costs? Household housing expenditures are greater than transportation expenditures, mainly automobile expenditures, Table 1. The lesson is that the off-system problems can be very consequent i a 1 . As was the case for on-system congestion costs, the problems fall on specific qroups. In the housinq case, it is those entering the housing market and low income families generally. Interestingly, the about 30 percent of expenditures on housing, shown in Table 1, has not changed greatly over the recent decade. That's mainly because of the limited incidence of increased costs.

Table 1: Major Personal Consumption Expenditures, 1984

I tern	Percent
Housing	30.2
Food	18.7
Transportation	12.7
Health	11.4
Recreation and Leisure	9.5

From time to time, the real estate sections of California newspapers compare housing costs in California with those elsewhere. Data from the Northern California Real Estate Journal were published recently (15), and are presented below in Table 2. As may be seen, only about 15 percent of the households in the Bay Area have incomes high enough to qualify for the purchase of the medium price home.

Table 2, Comparison of Housing Costs:
U.S. California, and Selected California Cities, 1987

	U.S.	Calif.	Bay Area	LA	Sacramento
Median House Price	$87,000	$141,543	$173,080	$141,856	887,276
Purchaseable Percent*	46	30	16	27	50

*Percent of households with incomes high enough to qualify for financing.

Assuming that the U.S. median house price represents a good access situation and that houses are about the same everywhere, rough statements may be made about the costs of off-system congestion defined on housing costs via land costs. Costs are high in California generally and especially in the Bay Area. The access situation in Sacramento is good.

That rough calculation ignores developer fees of many types, and fees vary among cities in California. It also ignores the special situation in the Say Area where topography limits usable land. It could also be pointed out that demand for housing in California is strong because of growth pressures. That is true, of course. But it yields high hdusing prices because of supply limitations.

What's the lesson for dealing with congestion? The off-system congestion problem as it is reflected in prices for houses in California is great in California generally, yet is variable amonq places. From the land supply point of view, the need is for those on-system operations improvements that would expand the land supply. Although we have not made a qualitative estimate of the magnitude of improvements needed, it appears that major improvements are needed.

The off-system congestion problem is also reflected in flat or negative productivity trends in housing construction. Highway service improvements to increase the efficiency of housing production are unclear. Service improvements may or may not follow from the on-system improvements that would increase the land supply.

END

As pointed out at the beginning of this report, it is part of a continuing study. For this reason, no summary statement5 are made.

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