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Innovation and Transportation's Technologies

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William L. Garrison

I critique the innovation processes that yield transportation's technologies, and to aid my analysis I look back to take advantage of the accumulation of experiences and insights marked by the millennium

I identify supply, transport, and user systems. Transport systems move things, supply systems provide fuel, pavements, and other inputs to transport activities, and user systems combine transport with other activities for socially useful purposes The discussion then shifts from structure to behavior, and a short review of the emergence of today's systems reminds us that technological advances may improve the provision of old services, offer new ways of doing old things, or induce qualitative changes that enable doing new things

With these structural and behavioral matters in mind. I challenge the reader to judge the present situation and the future

Introduction

I seek a broad and constructive critique of transportation's technologies, and I will take advantage of the accumulated experiences and insights marked by the millennium Yesterday's innovations, the transformation of old systems to new ones, and other experiences gave us today's systems. Rich histories of transportation tell us about the evolution of the systems and how enhanced services have done marvelous things for us. The variety of services has increased and enabled users to do old things in new ways and do new things Today's world isn't imaginable without transportation services.

But questioning is in order for neither history nor logic guarantee that marginal additions to systems or improvements to their technologies will continue advances, and the contrary may be the case. So while my critique will be informed by the past and present, it will question

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extending today's work into the future. My critique will not address investments in technologies providing products and services serving unworthy or unenlightened politics. Avoiding dwelling on yesterday's misadventures and those under development and deployment today, it will look around and forward with hope rather than cynicism

And I'll be striving to make sense of many stories because services are provided by large technological systems comprised of interlocking supply, transport, and user systems, as well as myriad subsystems. Consequently, stories about how transportation's technologies grow and develop are chapters in a complex book. The stage is large and the scenery varies, the cast of characters is enormous, and there are many subplots There are stories to be told about both necessity as the mother of invention and invention as the mother of necessity.

How to proceed with this formidable task? Technology development is shaped by what folks think and technology shapes what folks think The actors. judges and juries in the technological drama sort into advocates/enthusiasts, skeptics, and those who accept things as they are--go with the flow, so to speak. I'll begin by listening to today's enthusiasts and skeptics and then address the structure of systems. Technology development processes within systems are then treated. When considering the growth and development of systems, the emergence of services that are qualitatively different from precursors will be emphasized. Qualitatively different services increase users choices and enable the emergence of new production and consumption activities. As Saviotti points out for activities of all sorts, variety enables social and economic progress (Saviotti, 1996).

Sweeping metaphors will be useful, so I ask that a stage and a drama be imagined. Technology development will unfold in acts, and I'll give running commentary on how development unfolds. But first, who is doing what and how are we doing?

Looking Around; How are We Doing?

Enthusiasts see amazing progress everywhere, and their lists of today's 1,001 technological delights are mind boggling. In just a few years a collection of references on intelligent transportation system technologies has grown to some 15,000 entries (Hernandez, 1999). The new products pages in *Research and Development* and similar magazines and newsletters tell us about advances in other arenas.

Suppliers are seeking markets for the application of computer, information, sensing, and control technologies. There is interest in carbon-fiber reinforced structures and uses for other new materials, lubricants and fuels are improving in quality, improved tunneling machines are aiding construction, winglets are improving aircraft aerodynamics, and global positioning systems applications are spreading through the modes. The list of technological improvements in automobiles, ships, navigational aids, pavements, and traffic management goes on and on.

There is lots of hype, and hype is neither a new disease nor does it prove anything. Sixty-five years ago when sorting-out advances in ship technology, Gilfillan remarked on how powerful backers promote ideas in "our age of propaganda" (Gilfillan, 1935, p. 78). Many can recall the decades during which it was claimed that atomic power would provide free electricity for all. Laying the groundwork for his analyses of ways to improve forecasting, Schnaars includes claims for transportation among his examples of the "overevaluation of technological wonder" (Schnaars, 1989, pp. 9-34).

Enthusiasts are responding to markets for cheaper, faster, better services. But when markets are found, some innovations have more sweeping consequences than others. How are we doing? Are we taking small steps to the sound of old drummers? Are we producing what Mensch calls pseudo-innovations, things of much hype but little consequence (Mensch, 1979). Are revolutionary improvements underway or waiting in the wings, as Andersson proposes after looking back at waves of communications and transportation development (Andersson, 1989).

Titling the drama no less than a "technological revolution in transportation," U.S. Secretary of Transportation Rodney Slater mentions high speed trains, tiltroter aircraft, and intelligent transportation systems (ITS) (Slater, 1999). He promises technological leadership by the Department, and he projects $7.4 billion in operating-cost savings over the next decade from the deployment of ITS, as well as savings from avoided infrastructure investment. A cynic might take Slater's operating cost savings and estimate per capita savings in operating costs of about three dollars per year. Someone else might say that equilibrium adjustments to congestion and other processes are overlooked and conclude that the calculation is much too simple. Is a richer statement of the processes at work needed?

At the business-as-usual, small-steps scale are the savings projected from investments in research resulting in improved specification of the properties of the rail used by railroads (Guins and Hargrove, 1999). Between 1985 and 1998 American railroads invested about $30 million in rail research. Calculated on the longer life of rail, there have already been savings and an additional billion dollars in savings are expected between years 1999 and 2008. In addition there have been reduced derailments, and stronger rails permit increased use of 110 ton and heavier cars.

But the linkage between research and longer lasting rail is clouded by improvements in maintenance and rail lubrication. Also, the internationalization of rail supply occurred. Competition has increased, and the railroads have been able to purchase cleaner, straighter, harder, and easier-to-weld rail at competitive prices.

As these telling anecdotes remind us, technology is not the only source of improvements and there are system relations that require consideration.

Naysayers and Those Who Say "Prove It"

Naysayers of various stripes counter enthusiasts. At the extreme there is the view perhaps best stated by Jacques Ellul--the view that technology is a thing apart, an independent system that structures and controls the entire world (Ellul, 1964). Deleterious effects accumulate in an untenable fashion. Quoting Ellul's views on the ways technology is different from the natural world and is likely to destroy it, Kirkpatrick Sale sees technological negativism as a symbol and as the result of the downsides of broad social and economic changes (Sale, 1995). His view seems close to that of General Ludd's followers in the early days of the industrial revolution and their view of machines as a symbol of unwanted changes. Are today's strident complaints about transportation rooted in resentment of sweeping societal changes?

There is the pessimist's version of naysaying It gives technological advances low priority compared to institutional and policy matters. Thomas P. Hughes, the Dean of American historians of technology, remarks on the loss of enthusiasm for technology and expresses concerns about the future when closing his glowing work on a century of enthusiasm (Hughes, 1989). The buzz doesn't seem to be there so much today, and professional opinion says engineering is "being devaluated in all developed countries" (Bras, 1999, p. 15) If such laments apply to the world of transportation, is it because their technologies have little new to offer society? Is it because aging yet polished technologies fit the modern world rather poorly?

Finally, there are those who ask what do the data say? Technology serves to improve how things are done--give us better, or better-more, or some such for less. If transportation's technologies are improving, we should find productivity improvements when outputs are divided by inputs.

Are improvements in technology accelerating economic growth? As recalled from Economics 101, growth in output is imagined to be driven by increases in capital and labor inputs, Output = f(K, L). Residual growth above that calculated when regressing output on inputs is imagined to result from technological change.

Computer and information technologies are increasingly cheaper, faster, better, and they have been presumed to be a major productivity growth driver. However, a full study of the technologies and their uses found evidence of productivity growth elusive (Committee to Study the Impact of Information Technologies on the Performance of Service Industries, 1994). The widespread adoption of the technologies is undeniable. It is their contribution to more efficient production overall that is elusive. Long lag and learning times are among the postulated reasons for elusiveness (Sichel, 1997, pp. 32-36). Also, and certainly true to some extent, management and labor may be sequestering the gains.

Other studies reach a similar conclusion Accounting for changes such as improved education of labor and investment in new machinery, Gordon has estimated that only 0 26 percentage points in the growth rate of Gross Domestic Product in the 1988-1996 period should be attributed to technological improvements (Gordon, 1999). Jorgenson and Stiroh find that computers contributed about 0.16 percentage points to the growth rate during the 1990-96 period (Jorgenson and Stiroh, 1999). Putting those estimates together doesn't leave much for transportation's technologies, much less advances in other sectors. The cynic's projection of modest savings from ITS deployment and use fits the scales of these estimates.

The approach used by the economist is attractive, but I am uncomfortable with the assumption of a statical world with fixed production (or cost) functions and allowing only changed proportions in given recipes (movement along the production function). Technology lets us do old things in new ways and do new things, and a new production function is in order (Rosenberg, 1976, pp. 62-66). Also, available data give much more attention to agriculture, forestry, mining, and early varieties of manufacturing than to more modern activity sectors. Applying data on old things in old production recipes may miss the point.

The situation is similar to that in project analysis where most agencies and firms use some variety of benefit/cost calculations. Debates about such measures usually center on interpretation and execution of cook-book approaches and evaluation of environmental externalities. Yet following in the footsteps of Wellington, transportation analysts recognize that projects have multiple parts that need to be configured to circumstances and that partial analysis is not appropriate for large projects (Wellington, 1906). Big changes, say, on the order of the Channel tunnel, call for recognition of system effects, uncertainties, and monopolistic or other dysfunctions of facility ownership and operations (Quinet and Vickerman, 1997).

Commenting on Fogel's claim made in 1964 that railroad transportation had little impact on America's economic development, Paul David makes an even broader point in his chapter "Professor Fogel On and Off the Rails." He comments that the far reaching linkages of transportation call for a general equilibrium scaled analysis (David, 1975, pp. 291-315). Ville mentions changes in technology, industrial location, and raw material inputs in his review of transportation development in Europe (Ville, 1990, pp 166-171).

Before leaving production function-based productivity studies, I need to acknowledge the availability of studies of the transportation modes. About ten years ago I took stock of available studies (Garrison, 1989). An up to date review would reveal no good news, with the exception of the railroads where a recent analysis of measurement options and survey of studies reports several percentage points of annual productivity growth in recent decades in most nations, although the contribution of technology isn't emphasized (Oum, Waters, and Yu, 1999). There have also been studies in which public capital is explicitly identified, a subject of great interest to the Federal Highway Administration and highway investment advocates. A recent study found that investments prior to 1973 worked to improve the productivity of those industries that use vehicles relatively intensely (Fernald, 1999). That's no surprise for truck sizes have increased, and Keeler and Ying had already shown how improved highways increased trucking industry productivity (Keeler and Ying, 1988).

How are we doing? Having been innovated and deployed some decades ago and now pretty much providing services everywhere, transportation technologies are rather set in their ways and long in the tooth, so to speak, so perhaps modest technology-based advances are to be expected. The dismal conclusion follows that because advances are modest, transportation's technologies aren't doing much to make life better.

But considering advances in knowledge, technological capabilities, and market growth, the inverse could be argued. Indeed, failure to carefully specify the processes at work may blind us. To explore this speculation, I will examine (1) the workings of innovation processes within supplier. transport, and user systems and (2) the social and economic consequences of those processes. If innovation doesn't improve the human condition, it has no value. There is no technological advance.

The Stage

I imagine the innovation and technology development Drama taking place on a stage. How is the stage arranged, what's its structure? I imagine three systems on stage: input, transport (movement), and user (Figure 1).

Input ←→ Transport ←→ User

Fig. 1. How Transport Systems Interact with Supply and User Systems

This broad scheme accommodates the reality that the transportation technologies are what transportation folk and the public take them to be. Major newspapers in the U.S. sometimes use transit as an inclusive term for all the modes; Americans say transportation when many others say transport. For the modes, there's short sea, transit, air, auto, barge, and more, but the list does not extend to travel in space, the transmission of electric power, or the distribution of potable, irrigation, or waste water.

We don't generally look inside the factory, warehouse, or farm, and few other than public works professionals think of transportation systems as infrastructure systems

I will use familiar jargon when pasting the word system here and there--pasting it on highways, airports, and more. That usage should not be confusing even though I will use the three articulated systems notion when precision is needed.

I think of the transport system as where the rubber meets the road or the plane parts the sky, so to speak. The transport of people and goods is accomplished as operators use vehicles on facilities. There is no mystery about that simple idea.

And there is no mystery about the inputs to transport systems. Each transport system has an associate set of input factors, systems, activities, or industries--input systems for short. The air system, for example, uses inputs from air frame and engine manufacturers, airport planning and construction firms, insurance and financing organizations, and more and more. Such inputs are combined in the air transport system, and transport service is provided using equipment, fixed facilities, and operations protocols. Aircraft are the major equipment component, and there are airports, radio ranges, and other fixed facilities. Airline firms, labor organizations, and traffic control actors are involved in operations.

Turning now to outputs, there is reference to such things as passenger miles of travel, ton miles, or expenditures. These are level-of-effort measures. They say that society is willing to expend resources for transport services but not why. We all know that, yet I am reminded of *mokita*. It is said to be a New Guinea word describing something that everyone knows but no one talks about. It will help to recall what we all know but don't often say about how services are used.

Except for recreational, "joy riding-like" activities, purposes are achieved when transport systems are combined or embedded or recombined in using systems. I will make much of the using systems notion for the bottom line for questions about transportation technologies has a what-have-they-done-for-me-lately content. Are improved services enabling my combining transport with other things in ways that make my life better?

The user systems concept is not new, yet it seems to be out-of-sight and out-of-mind. DuPuit must have had something like this in mind when he said, "The ultimate aim of a means of communication must be to reduce not the costs of transport, but the costs of production" (DuPuit, 1844). Perhaps the ways transport and communications enable innovation and connecting/interactivity developments seem far afield from everyday concerns.

Peter Mackie recently remarked that transportation professionals talk about ridership, capacity, costs, and facility design and they are unresponsive to what politicians and policy makers have in mind when they emphasize development (Mackie, 1996). As I see it, transport folk talk about input or transport systems and politicians and promoters have using systems in mind. Are the differences in views obscured by overlapping words and phrases?

The point I am making bears emphasis, so I'll underscore it with examples. In a book on technological change in large systems Braun and Joerges discuss how air and surface transport services combine with other building blocks in the design and operation of the European organ-transplantation system (Braun and Joerges, 1994). Other building blocks include tissue matching, communications and information systems, and hospital and administrative arrangements.

The emphasis is on how transport may be combined with other things to form user systems that enable doing useful things. Of course, the combining process may not run smoothly and may lead to differing outcomes here or there. Although building blocks are available in the U.S.. the U.S. organ transplantation system is fragmented among regions and generally favors rural rather than urban patients. It is rather different from the system described by Braun and Joerges.

Braun and Joerges refer to the European system as a second order system; it is a user system in my jargon. They also say recombining rather than combining. That's reasonable. The transport system combines equipment, fixed facility, and operational building blocks to provide services. The services provided can then be thought of as combining (recombining) with still other building blocks to increase choices and social and economic welfare.

In a sweeping study beginning with the delivery of medical services by visiting physicians in the 1920s, Richard Morrill traced how improving highway services and travel by patients enabled the evolution of modern hospital and clinic complexes, as well as the specialized practices they host (Garrison et al., 1959). There was the reorganization of services, as well as the specialization and economy of scale enabled by improved services.

Ron Bantjes tells us about how automobile and truck services combined with family life on the Canadian Prairies and changed the nature of schooling, shopping, and many other things (Bantjes, 1992).

Does it matter that user systems seem out-of-sight and out-of-mind in most transportation dialogue? Does out-of-sight suggest that user systems improvements are nil these days? Is out-of-mind of no matter because the elasticity of demand notion lets us make inferences from tariffs and counts of cars, air passengers, and tons of freight and there is no need to inquire further? Is that all there is to induced traffic notions?

Does structure adversely influence technology adoption and use? Many input system actors such as construction contractors and aircraft manufacturers are large and politically powerful, as is government when it serves as a provider of facilities. Many transport system actors such as taxi-service providers, trucking firms, and individuals are not such titans. Are users' innovation possibilities constrained by what input system providers make available and thus the variety of services offered by the transport system? Do power asymmetries lead to dysfunctions in the development of transport technologies?

The dysfunctions question seems reasonable, and, as the newspapers do, most anyone can make a long list of suspected dysfunctions. Henry and Quinet's remark about French railroads, "The vertical quasi-integration between SNCF and GEC-Alsthom can be said to induce too much technical progress," is an example of the "too much" criticism by transportation folk (Henry and Quinet, 1999, p. 122). There is also said to be "too little" technological progress because suppliers are too small or too fragmented, a dysfunction highlighted, for example, in the rhetoric of federal transportation policy (U.S. Department of Transportation, 1990, p. 104).

I'll will pass on a fuller discussion of structural dysfunctions in favor of treating innovation in the context of the growth and development of systems. Interpreting the past and present calls for the sprinkling of definitions here and there as they are needed and the continued use of metaphors to corral descriptions, ideas, and processes.

Transport Systems on Center Stage

Recalling the Drama metaphor, imagine transport systems on center stage with supply and user systems hidden by partially opened curtains. Anticipate a play in three acts. The acts unfold as systems are innovated and then deployed and capture their markets. In the final Act systems exibit maturity and stasis while fending off competitors and sailing in the sunshine of their obsolescence, recalling a remark made about clipper ships at the beginning of the steamship era. Settle into your chair, the unfolding Drama takes many years. And the Drama gets complex as is seen when Figure 2 adds the life cycle dynamic to the structural template.

The Systems

		Input	Transport	User
System Behaviors	Innovation			
	Deployment			
	Stasis-maturity			

Fig. 2. Cross Classification of Structural and life Cycle Behavioral Properties

Already, there are nine intersections to be investigated, and the addition of five or six modes overwhelms, so I will stay at the Drama only long enough give a sense of the processes at work. Anticipate a Greek tragedy: things start out well but turn out badly.

But when the Drama begins there is no empty stage to be seen. Some sort of transport is always present. Exciting times are when newly innovated systems burst on the stage and push others aside. I think of the newcomers as qualitatively different because their differences go beyond being cheaper and/or faster. They enable doing old things better, and as they enable doing old things in new ways and doing new things they innovate their markets. By offering new choices, they enable social and economic development.

"Burst on the stage" is an occasional thing. Running the video fast-forward, most of the time transportation technology is seen to be moving along an equilibrium path with change driven by Darwin-like processes. But from time to time the path is interrupted by discontinuities and branches or, as is said today, punctuated by the emergence of qualitatively different systems. The presence of punctuated equilibrium in natural systems is debated by natural scientists (Somit and Peterson, 1989), but something like that is clearly present in large artificial systems such as transport systems. It is also clear that system innovation is the mechanism when punctuation, branching, or revolutionary change occurs.

Great Men, Great Events Model

One model of how systems are innovated is the "great men, great events" model. We recall the building of Governor Clinton's Erie Canal and various emperors' Roman roads and we associate Stephenson with the railroad, Fulton with steamboat services. Benz with the automobile, air services with the Wright brothers, Sprague with the trolley, and some 5,000-years-ago Sumerian with the service that could be provided by a wheeled bullock cart. The list of heros varies somewhat from nation to nation. Should America's Stevens get railroad credit? Peugeot of France for the automobile? But what is meant by automobile? Wasn't the Panhard the first car with modern features?

Where to draw the line? What's to be recognized? I've examined a chronology that recognizes something over 5,000 folks and things, and I can think of omissions (Bruno, 1993). But without a sense of how things fit, lists just position things in time and say little about why and how one thing triggers another

Basalla emphasizes functional themes. In the course of discussing the transistor, for example, he traces its origins to crystal detectors developed in the 1870s and notes that imagining its functions was influenced by precursor vacuum tubes. Basalla remarks that "Any new thing in the made world is based on some object already in existence" (Basalla, 1988, p. 45). Extending from Basalla's object to technological systems, I regard objects and ways of doing things (know-how) as the building blocks for new things.

So with all due respect to creative folk and well known events, I have to say that the great man, great events model doesn't tell us enough. The discussion to follow will mention creative folk, so I'm not dismissing their roles. The discussion will place emphasis on things/objects and know-how as the building blocks for innovation.

Market Niche and Convergence-combining Model

The appropriate model, I think, emphasizes convergence, learning, combining, and market niches and the ways those and other words characterize steering the new growing out of the old. Let's talk the process through using the Stockton and Darlington Railway for illustration.

Its market niche was formed by coal deposits in the vicinity of Darlington that might be moved through the port at Stockton to the market at London The elevation of the deposits made canal building and operating expensive, and the distance to Stockton aggravated the cost of road transport. Landowner Edmund Pease imagined a tramway with horse drawn wagons and engaged George Stephenson as engineer. Stephenson had some experience with steam locomotives, and to make a long story short, many say that the railroad era was announced on September 27, 1825 when a locomotive pulled a train from Darlington to Stockton. There was a convergence of steam power, tramway-like facilities, and other things.

It wasn't the locomotive or the pulling of cars that announced the rail era. That wasn't new. At least 20 years earlier, Oliver Evans in the U.S. had harnessed high pressure steam to create a mobile dredge, and at that time Richard Trevithick and William Hedley had used locomotives to pull passenger and coal hauling wagons. It was the successful large scale design, the combination of things, that was the innovation.

What were the building blocks of the design? The market niche, tramway-like facilities, and locomotive have been mentioned. Other building blocks included commodity tariffs, tolls, and other features of canal operations, as well as the institutional and technical expertise held by canal contractors. Venture capital was involved.

It was a people thing too. George Stephenson deserves his fame as recognized by his likeness on an English bank note. Edmund Pease and his son who moved in Quaker financial circles and other land owners and supporting actors played their roles. And market niche and situation mattered. There were the coal fields around Darlington and difficult terrain to be crossed. More broadly. there was the market for coal formed by increased use of steam engines especially in the mills of the budding industrial revolution, and also in the cities whose growth was accelerated by the commercial and banking revolutions.

The attention paid to Stephenson and railways by historians is well deserved. I like Jeans' 1875 book because of its attention to both Pease and Stephenson. The British railway story serves us well because it and its context have been so well documented and interpreted (e.g., Aldcroft and Freeman, 1973; Dios and Aldcroft, 1969). Everything anyone would want to know is summarized in the singular *Companion to British Railway History* (Simmons and Biddle, 1997).

I said that the great men-great events model doesn't work as well as combining and market niche thinking. But having said that, praise was lavished on Stephenson and Pease. That's not a contradiction, for I think of the combining and market-wise thinking as the message and individuals as actors at the Drama. As we will see as other creation stories are mentioned, sometimes actors are visible and sometimes they are not, though they are always there.

There is a creation story for each mode. Perhaps I should say stories because they unfold differently depending of eye of the viewer, and there is a certain amount of national chauvinism shaping what is seen and said. No matter. Using an expression attributed to Yogi Barra, "it's just deja vu all over again." Schumpeter's insight of about combining ruled. He saw progress as the "carrying out of new combinations" (1934, pp. 65-66). More recently, Satchell has referred to innovation as ".. a successful embodiment of ideas...rearrangement of the environment such that ideas become tangible, useable, and useful" (Satchell, 1999, p. 41). Pacey refers to innovators' modifications to fit environments as opposed to large institutions seeking improvements by doing more of the same (Pacey, 1983, Chapter 8).

Let's recall some combining stories that vary a good bit but still have common features.

Fulton's operation of his steamboat on the Hudson River wasn't the first steamboat service offered; there had been trials and modest successes elsewhere. It was the market niche that got it right. His father-in-law provided financing and much of the political muscle Fulton needed for economic success. There was nothing special about the technology. Paddle wheels followed from waterwheel experiences, a low pressure, and I would say obsolete, Watt-Bolton engine provided propulsion. Operators already offering sailboat services had identified the market and the tariffs that could be charged.

Moving to Pittsburgh at the head of the Ohio River, Fulton strived to repeat his success, but the nature-provided guideway didn't combine well with Fulton's low power equipment and he was also unable to obtain monopoly advantages. The innovation of services on the Ohio-Mississippi Rivers involved actions by other actors, especially Captain

Shreve and his clearing of snags with federal government assistance. Fulton certainly deserves credit, but inland waterway services built from facility improvement innovations, as well as the steamboat.

Modern ocean services turned on combining paddle wheels, the screw propeller, steam engine and sails, iron and then steel for shipbuilding, and government subsidized mail routes. The steam hammer and advances in shipbuilding were important. Brunel was perhaps the best known actor, although like Fulton his success was mixed, and lot of credit ought to go to those who financed, took risks, and operated services. Again, this was a situational thing, with the North Atlantic, Baltic, and other niche markets calling for different combinations of equipment, ports, navigation aids, and services.

In water-born services generally there is variability stemming from canal, river, coastal, and ocean route situations, yet combining remains the common feature of the origin of modern services.

Airplane-provided services were imagined early in the 1900s, but a workable combination wasn't found until the 1930s. Building blocks available then included airline firms, aids to navigation, airports, and knowledge of markets. Some say that Donald Douglas and his corporation's Model 3 (DC-3) was the innovation that created the industry. But not so fast. The other building blocks were there and a variety of aircraft were under development to enter the combination. Indeed, an earlier Boeing model (B-247) had many DC-3-like features yet failed on too slow and too small and too short range for the New York-Chicago market niche dimensions.

When jet aircraft emerged in the 1950s the swept wing, jet engines, and jet engine wing pods were combined with descendants of DC-3-type aircraft. Other DC-3-shaped building blocks--firms, air traffic control protocols, and airport financing--combined with the emerging aircraft form. It was a force fit, so to speak, because jet aircraft requirements strained the existing combination (Gifford and Garrison, 1993).

Although a fuller discussion would look back to early canal and road days, say something about automobiles and trucks, cover urban systems such as subways, and treat pipelines, I'll not touch on more examples because the pattern repeats.

Products of the Times

The first Act of the Drama has been presented as a series of innovation-by-combining stories. As the curtain comes down on the Act, the intermission allows for a round of criticism.

As we have seen, transport technologies emerged as a product of circumstances and the building blocks available at times and places, and "what if" speculation suggest that things might have evolved differently if, if .. If a condenser had been available for steam automobiles at about 1900, then . If Brunel had gotten his 8 foot gauge Great Western started earlier, then... If Fulton's steamboat had not been burned in Paris prior to trials there... The "ifs" go on

One "if" that has received a good bit of attention is the argument that if toll road operators had not blocked the development of steam powered road vehicles at about the time the railways got started, then motorized road transport would have taken off early on (Beasley, 1988). At the time, toll road operators were preoccupied with maintenance, damage by vehicles of differing sizes and weights, and damage-related tolls. So it is reasonable that they would have been concerned about damage from heavy steam vehicle operations. Eventually, steam powered drayage vehicles operated by firms such as Pickfords, and mobile farm machinery had modest successes.

An "if" in the same vein was steam tractor-hauled wagons from Nebraska to Colorado beginning circa 1860. Although the market was there, there were some start-up problems, and, aided by government subsidy and loans, the Union Pacific Railroad captured the market before road haulage was given much of a trial (History of Cargo Trailers Consortium, 1999). Here and elsewhere, does the race go to the first off the starting line rather than the swiftest?

The point is that we are surrounded by "ifs " We take the contingent nature of systems for granted, and if contingent is even thought about, we reason that one cannot reverse history. Shaped by time and place, should we expect yesterday's systems to perform well in changed environments? Should past events and situations serve as an excuse for inaction?

I often hear that there is so much money invested in facilities that change is not possible. Stephenson and Pease were not dissuaded by the opinion that investments in roads, canals, and coastal shipping said that their improvement and expansion were the tasks for innovators. Such an argument delayed but didn't thwart the displacement of break-of-bulk shipping by container ports and ships.

I also hear that knowledge development leads and innovation follows. That's true in many cases as the solid state physics and transistor story tells us. But lack of knowledge is no excuse for inaction. If it was, then Stephenson would have had to wait for the development of thermodynamics, structural engineering, and materials science before building railroads. Perhaps a better rule is that innovation triggering the clamor of markets stimulates knowledge development.

Deployment/Diffusion of Transport Systems

Back to the Drama. The curtains open for Act 2 in which systems are deployed or diffused. There is something for most everyone. Enthusiasts explode with excitement as publics clamor for services, and roads, rail lines, harbors, and other facilities spread here and there. The objections of naysayers, such as Charles Dickens in the case of railroads, are pushed aside, and technique oriented folk see diffusion processes amenable to mathematical modeling.

I've seen lists of model-based diffusion studies where references number in the 100s. Analysts assume a mathematical function of an S-shaped sort or derive one from notions about diffusion processes. For example, it may be assumed that the rate of growth is proportional to the growth already accomplished and that remaining. The word-of-mouth telling and demonstration-of-success process is well known and appreciated (Hagerstrand, 1952). Karschenas and Stoneman illustrate approaches by economists in their 1995 essay. Arnuf Grubler's inclusive, valuable book has provided innovative and widely scoped analyses of the diffusion of transportation and communication systems (Grubler, 1990). He emphasizes the comparative dynamics of systems, and he touches on related topics such as long waves in the economy. The dynamics of growth, the regularity of patterns across modes, the role of energy, and the differential paces of development of physical infrastructure and equipment are treated very well by Nakicenovic, who also considers substitution processes (Nakicenovic, 1986 and 1988).

Building on the insights of Grubler and his associates at the International Institute of Advanced Systems Analysis, Theodore Modis has conceptualized laws of natural growth involving competition, diffusion, and innovation (Modis, 1992). He finds that 56-year cycles apply to lots of things, including long waves in the economy. I've looked at some of the modes, and working with Reginald Souleyrette have also tied the spread of transport services to long waves in the economy (Garrison, 1989) (Garrison and Souleyrette, 1996).

This considerable and well crafted literature says, essentially, that cheaper, faster, better services displace what went before. It also says that improved transport services may drive the upswings of long waves in the economy. The literature provides some intriguing regularities--passenger rail services are adopted more quickly than freight, nation-to-nation rates of diffusion seem to depend on prior experience elsewhere, and one wonders why Modis' 56 year cycle for the waxing and waning of systems applies so widely. An extended discussion is invited, but I will pass in favor of emphasizing innovation and technology development.

Pull Back The Curtains

Transport systems are on center stage, and the audience applauds unfolding S-shaped diffusion curves and enthusiasts are inspired by shiny automobiles and fast trains and aircraft. Yet there is more to the Drama, for technological formats are evolving as diffusion proceeds--the Model-T Ford on a dirt road becomes the Belchfire V-6 on a freeway and the small, slow passenger plane goes supersonic. Indeed, innovation continues as markets expand and as experience tests alternative production formats. Examining several transport systems, Sahal shows how demand pulls and shapes innovations as systems grow (Sahal, 1980). Users choices increase and we see diners in Hong Kong eating fresh lettuce from California and tourists vacationing in recreational vans.

There are roles for supply and using systems, so I pull back the curtains so that they are also on the stage. How are they shaping development?

As already discussed, transport systems use technologies produced by suppliers. and improvements in services are slaved to suppliers' technological advances or the lack of them. Suppliers provide substitutes for something available before, such as the substitution of artificial rubber for natural rubber, the diesel-electric for the steam engine, and the jet for piston engines. Substitution makes for cheaper, faster, better.

A supply emphasis is widely held. For example, the 1995 *Biennial National Critical Technologies Report* identifies transportation as one of seven critical technologies areas. When highlighting intelligent transportation systems, it refers to the "capacity to alter the American transportation system" (Office of Science and Technology Policy, 1995, p. 123). Also, service improvements are to flow from innovations in propulsion. Across the board, supply system improvements are seen as strengthening the international competitiveness of American industries.

I can't deny that society is served by suppliers actions to make services cheaper, faster, and better. But taking the long view do they block qualitative changes in systems? Hughes remarked that old systems suffocate new ones? (Hughes, 1989, p. 461). Is that because imagination is so suffocated by supply system actors visions of the here and now that alternative technological development paths are not imagined?

Everyone knows the drill. Supply and transport systems actors write mission statements, list objectives and goals, and then identify problems blocking progress. The sequence research-leads-to-innovation-and-technology-that-solves-problems is then triggered. This is a technological fix stance, and there is something in it for everyone--think tanks, universities, consultants, product suppliers, and system operators. The risk is minuscule that something would emerge making old arrangements obsolete.

Problems have changed somewhat over the fifty years that I have observed the process and the level of activity has increased considerably. Nowadays, there are the National Cooperative Highway and Transit Research Programs, the European Commission's Innovation Programme, the Airports Council International technical committees, and many other venues where thinking is in the research-begets-innovations-to-solve-problems style. There isn't much discussion of how research products become tools, nor does there seem to be follow-up on the results of studies. However, *TR News* does run How Research Pays Off stories from time to time.

How does the demand for transportation services enter? The view of demand most widely held imagines passenger trips by purposes and other attributes and shipments of different densities, sizes, and urgencies. Issues are those of elasticities as the attributes of service such as velocity and price vary. Put another way demand elasticity tells us all we need to know about user systems. That view is nested within the broader view that transport is an intermediate economic activity serving a fixed set of activities (Small and Winston, 1999, p. 11). Much is known about elasticities, yet one often hears build-it-and-they-will-come assertions that ignore measures of demand elasticity.

Is that all there is to it? Do these conventional views fall short as we strive for insights about transportation's technologies? More than that, might they distort the search for technology-based transport improvements?

Markets Pull, Supply Follows as The Two-Step Dance Proceeds

Instead of remarking as I have on productivity improvements in the national economy, shiny new artifacts, or diffusion curves, writing in the late 1700s Adam Smith remarked on how transport improvements increase the sizes of the markets and raw material sourcing areas (Smith, 1776). He saw specialization-associated efficiencies via the division of labor as the main outcome of the canal, ocean shipping, and road improvements of his day.

Today we see specialization and more, and I think of a two-step dance (Figure 3). The dance is pulled by the evolution of user systems and at first is enabled and later constrained by supply systems.

First Step. Innovation provides for cheaper, faster, better services. The variety of services increases and society has more choices among services. Folks are better off because increased variety allows choices closer to their desires. That's the thought when modal choice modeling asks if some new service is worthwhile

Cheaper, faster, better also yields the kinds of changes described by Adam Smith, and later emphasized by location economists and economic geographers.

Second Step. Improved services enable user system innovations as transport services are combined with other building blocks. That is, transport system innovation and deployment energizes innovation in user systems. Here is the big pay-off as transport improvements make for better living by enabling new production and consumption choices, increased varieties of goods and services, and such. Innovation becomes the mother of necessity as users combining transport with other things enable social and economic advances.

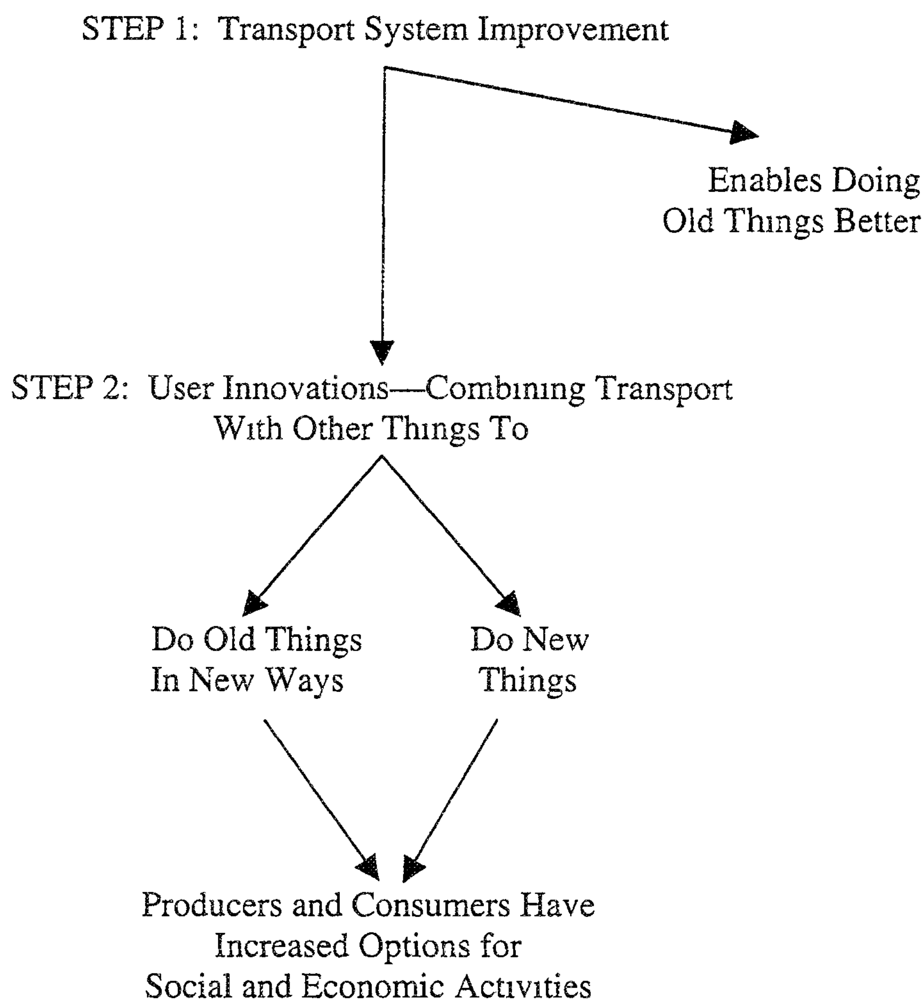

Fig. 3. How User System Innovations Translate Improvements in Transport to Social and Economic Benefits

Doing old things better? Urban drayage shifts from the team and wagon to the truck, and electric street cars substitute for horse- or cable-drawn trams. Old things in new ways? Instead of loading the wagon and driving cattle when setting our for distant markets in the fall, farmers send products to markets using merchants and receiving payments through the workings of banking and futures markets. New things from combing transport with other building blocks include the Las Vegas version of Thomas Cook's 1840s recreational activities, continuous process steel making, and ice cream in 31 flavors at neighborhood stores.

Working with others, I've identified many examples of transportation enabled innovations, and tied innovations to variations in the availability of services (Garrison and Souleyrette, 1996) (Garrison, Gillen, and Williges, 1997). Rick Szostak's comparison of innovation rates during the industrial revolution attributes the British lead over France to the availability of rail services (Szostak, 1991).

The transport system itself is a venue for doing old things in new ways. Communications, control, and connecting are key words. Vehicles scurrying here and there ask for communications and control technologies. All the modes create rules of the road and other operating rules to discipline and coordinate the behaviors of actors; communications and traffic controllers contributes to safety and efficiency. Soft technologies such as waybills and standards for rail car interchange and highway signs aid the connecting of parts of networks, and intermodal connecting has been aided by the innovation of materials handling equipment, as well as standardized containers. Today, ITS innovations are increasingly aiding operations.

Fast Forward to Full Deployment; A Greek Tragedy Plays Out

There is the sequence innovation, diffusion, and market saturation, and with market saturation comes stasis. This follows because once a transport system gets a start, it locks into a format. The pattern is this. Early building blocks may be honed or rejected and replaced during a period of trial and discovery. In the case of railroads, T-shaped rail mounted on ties emerged after trials with iron stringers on wood, fish plate, and other rail configurations on stone or wood blocks. Horizontal boilers were adopted, and lots more. Because of connecting cars in trains, among other things, the Stockton and Darlington shifted from a toll road, independent-operators format to a railroad-operating format. It didn't take long for railroads to take on their decentralized management structure.

Referring to the automobile industry, Abernathy coined the term predominant technology to describe the technological formats that emerge from trial and error and dominate practice (Abernathy. 1978). It is an apt term. Unitary technologies emerge from discovery of feasible products and their markets.

Early-on technological improvements rapidly lower the cost of services and improve quality. Reverse J-shaped curves describe the ways costs decrease as the discovery of new formats and fine tuning technologies improve production processes (Garrison, 1989) (Grubler, 1990, p 236)

But many of the characteristics of transport systems are incorporated in the predominate technology as best-for-the-times technological and institutional formats. They lock-in, and there is path dependence. As a result and as I have already suggested, when technologies emerge the race may go to the first off the starting line rather than to the swiftest, as the perhaps over-used examples of standard rail gauge and 60 Hertz nominal 110 volt electricity distribution illustrate.

Jonathan Gifford attributes lock-in to increasing returns, the benefits of use increasing with increasing use (Gifford, 1996). He points to large setup costs and the technical efficiencies that come from large scale production. Covering that ground, economists refer to the economy of scale achieved by firms, as well as to the economy of scope achieved as networks serve more and more diversified markets (Braeutigam, 1999, Katz and Shapiro, 1986).

Just looking around tells us more about the mechanism for lock-in. Consider decisions Once a system is on a development path, anything new has to fit the technological format. For instance, we see airports constructed to fit the equipment that will use them and the ways airlines and passengers make use of them. Ideas about new kinds of aircraft? They have to fit airports, air traffic control protocols, and what passengers and firms do. It is simple enough What is already there defines what is possible, and there is constrained, incremental decision making.

Innovation and technology lock-in has parallels in project implementation. There is a problem, and politicians and others pick an off-the-shelf solution from among examples they know about--high speed trains, light rail, park and ride lots, expressways, and the like. Planners are given their marching orders, and analysis begins. Instead of ready, aim, fire, the process is ready (sense a problem), fire (make the investment decision), and then aim (calculate facility use and benefits and costs). Charles L. Wright makes this point in his thoughtful diagnosis of current planning approaches (Wright, 1992).

Are techniques such as mode choice analysis simply polishing present conditions? Do locked-in supply and transport systems leave techniques with little to do?

Looking beyond the ways system structure and behavior constrain actions, habit of mind or focus of mind or blinders or misplaced faith or something on that order seems to me to be the root cause of lock-in.

Extant systems are taken to be the fittest. Let's get on with improving them, and constrained incrementalism defines the rules for improvements.

I have stressed the importance of variety for it makes options available to users Variety increases as transport systems are innovated and deployed. But as transport systems tend to stasis does lock-in become the enemy of within-system generated variety? To be sure aircraft of varying sizes and autos of different colors and horsepower are produced, but are they "same old, same old" from a service view.

Today and Tomorrow: Greek Tragedy Continues?

The curtain opens on Act 3 and the several transport systems are well deployed. Services are available just about everywhere they are economically practicable. All systems have lock-in properties that are jarred only now and then. As the Drama proceeds deregulation here and there lends excitement, and the coming on the stage of diesel locomotives, container and neobulk ships, jet aircraft, and deeper channels and larger locks on inland waterways also catch attention.

Some of these exciting improvements are enabled by market growth and economies of scale, improvements such as unit trains and neobulk ships. All improvements began as effective technological substitutions. Container shipping and jet services have forced system redesigns and have the combining features I associate with qualitative changes in services. They have energized innovations in user systems.

The impacts of wars, energy supply interruptions. and waning and waxing political fortunes seem not very lasting in the long term. Struggles over market shares are a continuing theme.

Problem management is driving technology fixes in all the modes: innovations to improve safety, reduce environmental insults, increase energy efficiency, ease congestion, and squeeze more capacity from facilities. Although options are constrained by system structure. opportunity grasping is also on the stage. Applications are being sought for communications, sensing, information, and computer technologies as competition motivates system managers.

Today's Communications/ITS Connection

What is the increasing use of electronic communications and related technologies (such as computers, sensors, and operations and management software) saying for transportation? Along with many other transportation professionals, I think of transportation and communications as close cousins. At first glance, that is because of physical and structural parallels--parallels such as network and capacity/bandwidth concepts.

The main consideration is that of role. Communications and transportation have connecting functions. They permit interactivity among social groups, markets, suppliers, recreational sites, agencies, organizations, and individuals. It is improved connectivity/accessibility that enables doing old things better and in new ways and doing new things. Indeed, the processes described by the two-step dance metaphor apply. Figure 3 and the accompanying discussion would work just as well if communications were substituted for transportation and the examples changed.

There is a supportive function, the ways transportation and communications work together to produce outcomes. I think of the ways early postal, coach and, sailing services enabled innovations by and trade among places and partners. There was the U.S. Post Office's development of parcel post services, the innovation of catalog shopping, changes in the fortunes of commercial centers, and much more. Beniger's stimulating book on the control revolution tells us about transportation and the telegraph, for instance, how continuous (as opposed to batch) iron and steel production was enabled when the telegraph helped define and link markets to production (Beniger, 1986).

Today there is lots of buzz about internet market places, and measures are beginning to be made on their size and function (Sanden, 1999). Transport is part of that package today, just as it was when the Royal Mail carried purchase orders by coach and wagons and canal boats provided for the physical movement of things.

So far, communications and related technologies bundled as ITS mainly have been seen as an enhancer of transport services, and there are parallels to the ways the telegraph enables the control of trains and radio and radar enable the control of aircraft Also, there is the vision of telecommunications as a substitute for transportation services. But recalling Stover's comment on how the railroads feared that the telegraph would eliminate the passenger service market and Beniger's illustration of impacts of the telegraph on markets for rail services, are current visions of the scope of communications/transport interrelations much too limited (Beniger, 1986)(Stover, 1987)?

Picking up on Shnayerson's pointing out Prince Albert's 1851 remark on how communications and transport had already erased the vast distances separating mankind, would it be useful to compare the magnitudes and generic themes of yesterday's impacts with today's (Shnayerson, 1996)?

Asking Again, How Are We Doing?

The earlier Section asking how we are doing reported analysis saying that small improvements that have little overall effect on the fortunes of the national economy seem to be the rule. But I pointed out that a system or general equilibrium view is needed and I speculated that the results of improvements may be hidden from view. I also pointed out that system suppliers, transport providers, and users have ever-increasing varieties of building blocks from which to forge improvements.

Building on those thoughts, Jerry Ward and I are completing an optimistic exploration of passenger and freight system opportunities (Garrison and Ward, 2000). It is our view that aging transport systems are ripe for improvements because of congestion and other conditions, including opportunities to improve urban living conditions. New train control systems and the pressures for larger heavier trucks and more varied types of personal vehicles suggest new service formats. We imagine new combinations that merge building blocks from today's systems with communication, computers, and other new technologies. Let the band onto the stage and we will all dance the two-step.

Our optimism and conjectures are counter to the wisdom that technological advances are not in the cards. A 1992 symposium on highway-related industry productivity measures, for example, hardly mentioned technology improvements as a source of productivity improvements (Federal Highway Administration, 1993). (But hidden on page 12 of the Symposium Report and not remarked on further is a reference by Paul Roberts to the difference between productivity growth in the general economy as a consequence of changes in transportation services and productivity growth in the transportation industry itself.)

As seems typical of the emphasis in today's literature, a recent symposium on the costs and benefits of transportation said nothing about benefits (Greene, Jones, and Delucia, 1997). By omission, that's saying that the technology isn't improving and providing increased benefits. Instead, negative externalities such as pollution, marginal and full social cost pricing, and the full costs of parking were among topics treated Folks are skeptical about positive externalities of any sort; innovations enabled by improved services are not imagined. But allowing for the possibility of something, it is said that appropriate consideration of demand functions will capture latent demand (Rietveld and Bruinsma, 1998, p. 71).

"Fighting to Stay In Place" is the way an observer of trucking services and logistics put the situation (Sparkman, 1999). He spreads blame widely for the stagnation of productivity growth, and most of the things he mentions, such as conflicts between pavement, structures, and truck weights and sizes, are typical of locked-in mature technological systems.

Exit Examination

Placing today's situation in the sweep of transportation development, the situation may be one of or some combination of the below. Make selections and/or present your interpretation of the situation, along with your answers to the 30 or so questions already asked. Answers will be graded in year 3,000.

1. Today's technology advances are of a technological fix sort. They are especially responding to safety, environmental, and energy issues, the congestion effects of population growth, and holding back entropy generally (keeping bridges from falling down, dredging silt from harbors, and such). Since that's about it, supply and transport system innovations aren't creating new services that open opportunities for user innovations.

There is technological excitement, especially of an ITS sort. But pasting ITS on locked-in system structures and ignoring user innovations may limit applications to "a blood out of a turnip" endeavors.

Yesterday's experiences are irrelevant as are notions of systems and systems interrelations. As a result, effort continues to be expended on *non sequiturs*, actions that are not based on experience and that ignore the structure and behavior of the systems. We have advanced the art of lock-in to where excuses for inaction, structural dysfunctions, and lack of imagination portend a future that is, at best, the polished present.

2. As Stephenson and other innovators were, we are blind giants. As a result of trying this combination and that and users responding by innovating away, qualitatively different services are emerging. But with our thinking and analytic abilities constrained by past experiences, we do not recognized the changes underway. We do not recognize that we are the future created by Fulton, Stephenson, and other innovative individuals and agents and that we are also creating futures.

We are in a hit or miss situation. Something will come along. The future will be shaped by the first off the starting line rather than the best that can be done.

3. Using experiences as a guide and taking advantage of the storehouse of available building blocks, such as electronic technologies, skills in risk taking, private entrepreneurship, and altruistic public sector actions, we will explore opportunities for qualitatively improved services. Steered by feedbacks as user systems are innovated and adopted, we will follow-up opportunities. Lock-in will be managed through continued renewal of institutions and user innovation-steered changes in development paths.

Using transport technology advances as an energizer of technology development generally and taking advantage of many other capabilities, we will be advancing along development paths marked by an ever increasing variety of choices for consumers of all stripes. With greater variety of services and less rigid service delivery systems, the notions of less developed nations and regions and environment insult become obsolete for there are many ways to manage problems and create opportunities.

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