Transportation Technology Supply

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The scope, characteristics, and functions of transportation are reviewed to define the structure of technology needs. The impact on technology supply of the independence or disjointedness of technology components—guideways, equipment, and operations procedures—is then investigated. Each technology component shapes its technology supply stream; technology options are limited to those compatible with component supply streams. System interdependence reinforces the disjointedness of components. Railroad research and test activities and technology-sharing strategies are compared to the structure of technology supply and needs.

This paper examines the demand for transportation technology and the ways in which technology is supplied. First, building on previous analyses (1-3), emphasis will be on how needs for technology and processes of technology supply are configured or structured. Next, a review of current work on railroad technology problems, as an example of needs and supply processes, will illustrate the usefulness of our analysis and provide an interpretation of the current railroad situation. Remarks will then be made on the U.S. Department of Transportation (DOT) and the National Aeronautics and Space Administration (NASA) technology-sharing programs for transportation. A new approach developed recently for the U.S. Department of Energy (DOE) will be contrasted with DOT and NASA approaches.

TECHNOLOGY NEEDS

Scope and Characteristics of Systems

The needs for transportation technology reflect the scope and modal divisions of transportation activities and the fragmentation of markets. Transportation is a large activity, engaged in by different modes. Although each mode has its distinctive needs for technology, a common need exists for technology of fixed facilities, such as highway and rail bridges and airport and highway pavements. Each mode serves many submarkets, which are represented by firms, governments, or households, each in varying geographical environments.

A technological tradition permeates transportation. Continuing technological change is central to the history and status of the current modes. This is partly why the technological professions play central roles in deploying and managing most transportation systems.

Transportation's technological content and technological history set the stage for high expectations of continuing technological evolution. Reviews of technological trends (4), popular publications (5), and discussions of activities to further transportation progress (6) or to deal with the problems of modes (7) often reflect those expectations. The current technology is viewed as a precursor for further development. By using increases in speed to measure technological progress, the shape of the precursor-driven development curve has been examined for aircraft (8).

Much of the literature on technology transfer concerns the size of the institution, serving as an incubator for technology development and transfer, and the links between actors and classes of actors. Most theories or models are cast in terms of a set of stages. For example, the scientist affects the technologist, who affects the sales manager and eventually the market (9, 10). Each stage in the chain has an associated requirement for time, work, and monetary resources. Evidence is considerable that small institutions are relatively more innovative than large ones (11) and that regulation highly distorts the technologies developed and their deployment (12). Regulation may shield modes from competitive market pressures, enabling a technology to be developed and deployed that otherwise would not pass market tests. Or, because of its special requirements, regulation may stimulate technology, or it may dampen competition and, thus, the development of technologies to improve the competitive positions of organizations.

In the deployment of technology products, transportation equipment and guideways are supplied by relatively large organizations that are regulated, usually by extensive standards for products. Here, we would expect a low rate of technology development. In certain cases, a number of small firms engage in the transportation business (trucking firms particularly). Households can also be considered small organizations; large railroads and airlines are at another extreme. Small operations could be sources for innovation, but because their products are not in hardware form, their innovations concern how transportation is used. This speculative point seems worthy of examination. Consider recent policy that has aggregated mass transit into large organizations, which operate according to public-sector rules. This policy may be unexpectedly stifling service innovations.

Not only has transportation been swept along by its own technology, it has interacted with other technologies. The technology of the steel wheel and rail, for example, was intimately tied to the evolution of the technology of steel making. Currently, the rail industry is constrained by the inability of steel manufacturers to supply higher-grade steels in bulk and at lower prices (13). The technologies used in automobile vehicle production have affected all manufacturing processes. Assembly line (Ford) and industrial organization techniques (General Motors) were adopted early. Cost controls, use of special tools, and preassembly have been adopted more recently (14).

Perhaps a unique feature of transportation has been its impact on the distribution of technological knowledge. The geographic sprawl of the transportation plant and transportation activities has brought the technologies of transportation to every nook and corner of the world. The technologies of woodworking for ships, the shaping of metal and machinery for construction and repair of rail, and, today, the maintenance of air and automotive vehicles have distributed technological skills widely. This role of transportation in developing human skills, which seems to have gone unrecognized in the literature, has important implications for public policy.

Transportation Functions

Transportation performs several functions. An old view of transportation is that it provides access to resources. Once transportation brought salt, spices, and dried fish from great distances; now it provides access to resources of forest, farm, and mine. Modern transportation also moves products from manufacturers to markets and provides human capital (labor) for manufacturing and business. The right of access to the transportation system, a right established in medieval times, seems based on this function of transportation. Transportation enables holders of resources to find markets, and it enables individuals to engage in work and social activities.

A related view is that transportation (along with communication) is the glue that enables and supports social and economic structures and processes. The role of transportation and questions about technology are intertwined with matters of social organization. Transportation does more than enable the use of resources; its role extends to the organization of production and consumption.

These views contrast with the view of transportation as a service industry. From this outlook, society engages in activities—from shopping in a supermarket to producing commodities from land resources. Transportation is the service that enables these activities.

Still another view is that transportation is a business activity: Transportation consumes inputs and produces outputs. The cost of inputs should be minimized, profits should be maximized, and prices should be based on costs.

These different perspectives of transportation, along with the history of transportation technology and the character of transportation institutions, explain much of the literature about the need for transportation technology. From time to time in the transportation community, an outlook exists that considers the steady unfolding of transportation technologies inevitable. The recent interest in high-speed ground transportation, supersonic transport, capsules in pipelines, and personal rapid transit is testimony to this view of transportation as a system that is continually renewed by technology. The view of transportation as a service is reflected in the current search for innovations under the paratransit concept; the view of transportation as an enterprise is behind pleas for technology to reduce cost, increase efficiency, and bring prices in line with cost.

Social, resource, and organizational views of transportation are more demanding and not usually reflected in debates. The current wisdom that the transportation system is in place (and all that is needed of technology are ways to repair, reconstruct, and rebuild) is, in these broad terms, wisdom that the evolution of social organization has ended and that sufficient resources are available to society—a view to which we do not subscribe.

TECHNOLOGY SUPPLY

Although transportation institutions have a high technological content and demands for technology are expressed in diverse ways, the supply of technology to transportation is constrained. A set of interlocking circumstances, mainly institutional in nature, seems to explain this condition.

Disjointedness

Each transportation mode is formed by geographically configured guideways, equipment or vehicles that operate on those guideways, and protocol or operations techniques that determine how the guideways and vehicles are used. Thus, transportation technology can be considered as a triad, consisting of guideways, vehicles, and operations. (In pipelines, the material to be transported serves as its own vehicle.) A striking feature of transportation technology is the disjointedness of this triad. A clear example is the highway system: Guideways are supplied by the public sector, operations are affected by the decisions of firms and households as well as by an ensemble of public regulations, vehicles are supplied by private manufacturers, and decisions about their purchase are made by private markets. In addition to the public sector roles of providing guideways and prescribing service, economic, and safety regulations on operations, the system is affected by many regulatory, tax, safety, and other regulations of the public sector that are not specific to transportation.

Decision making about technology supply takes on a disjointed, incremental character. The highway supplier, for example, makes technological decisions by taking the technology components of equipment and operations as given. Transportation planning, thus, is constrained. The manufacturer considers the methods by which vehicles will be used and the guideways on which they will be operated as given and supplies vehicles to fit. These actions limit technology considerations to incremental ones.

In the instance of the highway triad, the presence of differing public and private roles partly explains the disjointedness; there is a similar role division in air and water systems. For example, the air transportation triad is made up of publicly supplied airports and airways, public and private operations protocol, and privately owned aircraft.

Even those modes whose ownership and operations are not in the public sector exhibit the characteristics of disjointedness. A striking feature of railroads is the divisions within firms of those concerned with fixed plant, equipment, and operations. Management is constantly concerned about problems along the interfaces between divisions of technology. Some current problems are those of the productivity of equipment (a problem at the interfaces among equipment purchasing, maintenance, and operations) and the impact of heavy cars on rail (a problem at the interface between equipment and guideway).

Several additional factors assist in explaining why the guideway, vehicle, and operations components of the technology triad are disjointed. A major factor is the separate technological traditions of the components. Highways, fixed railroad facilities, canals, and airports are supplied as civil engineering technology; equipment is supplied as mechanical engineering technology. In each component, strong technological traditions influence practices to be followed and peer group communications apprise professions of the availability and appropriateness of technology. Technological traditions are less strong in the operations component. In some railroad and truck firms, a management tradition is followed, although most transportation management is professionalized on the job. Operations are constrained. Because of regulation, managers have little control over pricing and service, and operations are a matter of serving those who wish to be served, considering the nature of equipment and guideways available. Thus, compared to guideways and equipment, operations range from a well-identified entity in railroads and air transportation (although with a highly limited range of available options) to an extremely diffuse situation in the highway system.

As mentioned, the literature on innovation and diffusion regards the process as a chain or an interrelated set of stages. A notion of integration has been developed about linkages between stages, for example, between those involved in technology development and marketing and those in other interfaces along the pathway from innovation to final utilization (15). A high level of integration is desirable for effective innovation and technology transfer.

The disjointedness among the components of transportation technology blocks integration. When individual components are examined, integration is considerable, for component actors belong to similar technology peer groups and have similar self-images and purposes. But a disjointedness of the technology results because its components are not integrated. Some confusion exists on this point because integrated component pathways are sometimes discussed as if they implied an integrated technology system.

When integration within components is considered further, an additional property is revealed. In theory, integration includes the following linkages:

1. Scientist to scientist,
2. Scientist to technologist,
3. Technologist to scientist,
4. Scientist to market manager,
5. Technologist to market manager,
6. Market manager to organization management, and
7. Organization management to market.

Transportation is dominated by technologists, so technologist-to-technologist links are numerous. Because of regulation, there are also regulator-to-technologist links. In some modes of transportation, especially private firms engaged in air transportation and freight movement, close technologist-to-market links exist. But, by and large, integration is in a single form: technologist-to-technologist. This domination of technology-to-technology links distorts candidates for both innovation and implementation.

The main impact of the disjointedness of technology supply is the lack of a feasible market (and pathway to that market) for total transportation technology. Such total technologies would put components of transportation systems together in new ways or create entirely new triads of transportation technologies. But transportation institutions are arranged so that little consideration is given to such options, and no base of technological knowledge considers transportation in that fashion. Instead, existing professional groups who work in transportation (civil engineers, mechanical engineers, and physical distributional-logistics people) think of what they are doing as transportation technology. Everyone is doing transportation, but no one is doing transportation.

Standardization

The relationships between the characteristics of transportation systems and the supply of transportation technology are also significant; they too affect disjointedness. Transportation networks form systems, and the tasks performed by those systems demand a high level of standardization. Thus, operating rules, guideways, and equipment are usually standardized. This standardization affects the disjointedness of the technology, because actors and institutions involved with technology components communicate with their counterparts throughout their system. These component pathways speed up the diffusion of technology within components, but, at the same time, they establish peer group interrelations and standardization problems, priorities that may divert interest from consideration of the technology triad.

The impact of standardization on the adoption of technology is both a hurdle and a hazard. It is a hurdle if the technology is to affect systemwide activities because consensus is required on the part of many adopters before the technology can be implemented. This may bias the search for technology to that which fits the standards or to technology that does not have systemwide impact. Standardization is a hazard if it can force adoption of a technology regardless of its systemwide applicability.

Two examples may help make these points. Increased automation of railroad car coupling would be highly desirable. From a technical view, the connection of brake hoses and communication links should be quite practical at the same time that rail cars are physically coupled. Labor savings and other productivity gains would be great. But requirements of systemwide standards for coupling constrain the implementation of such a technology—for all users would have to adopt such standards before productivity gains could be captured. At the same time, standards can force adoption of a technology, such as those imposed on automobile emissions. In this case, the standards did not specify the technology, only the emission controls. The systemwide implementation of the standards thwarted the so-called two-automobile strategy, which would have implemented standards tuned to ambient airshed quality and, thus, different kinds of control technologies in different markets. (To some extent, the California standards versus the standards for the other 49 states accomplish this purpose.)

INTERPRETATIONS

We have characterized transportation technology needs, their development, and transfer; now we shall (a) examine an example of technology development and (b) review technology-sharing programs. The development of rail technology will serve as the example. Our question is whether the situation we have described holds. The review of technology sharing will examine its effectiveness.

Rail Example

A recent report of the Research and Test Department of the Association of American Railroads (AAR) lists AAR funding for research and test programs and funding from other sources. It provides a description of AAR research and test activities (16). To indicate AAR technology priorities, AAR program expenditures in 1975 have been sorted, and the effort was guideway, 15 percent; equipment, 29 percent; guideway-equipment interaction, 24 percent; operations, 26 percent; and safety, 6 percent (16).

Several caveats are in order. Expenditures shown were grouped in accordance with the discussion in the AAR report, yet there is a certain arbitrariness to the grouping, for a research program may have multiple products that fit several categories. Also, the relative attention given to technology topics in the AAR budget is surely dependent on the availability of supporting funds and work elsewhere, so this is only an approximation of AAR priorities. In addition, the percentages calculated may not approximate the relative level of effort on categories of technology throughout the railroad industry. Individual railroads do research and development, as does the Federal Railroad Administration (FRA). In addition, the larger part of a technology development and implementation effort (perhaps 90 percent) occurs after research and test activities.

These caveats notwithstanding, I was struck by the ease with which expenditures could be aligned with the guideway, equipment, and operations components of the technology; how programs were rationalized in terms of these component needs; and the lack of transportation work in the sense of considering the triad of components. The 6 percent of expenditures for safety research is not a very useful number. Safety is one aspect of regulation, bounding all research activities, but there is no way to neatly define research and test activities that are responsive to regulation.

An interesting aspect of the expenditures is that approximately one-fourth of the funds is used for guideway-equipment interaction—the track-train-dynamics program of the AAR. This contradicts expectations based on our earlier discussion, which indicated that technology development and transfer are component-oriented, taking place within components, rather than oriented across components. Additionally, operations received 26 percent of the research and test budget, which conflicts with the notion presented earlier that operations are the weak link in the technology triad. A partial explanation for the amount of work on operations is rail's organization into firms, in contrast with the institutional separation of components in air, water, and highway transportation.

TRB recently made a study of railroad research needs (17, 18). The study identifies research needs that contrast sharply with the research programs of the AAR. This is not surprising; AAR support of the conference suggests that it suspected its research program to be lacking. Also, the call for research by the TRB was not addressed exclusively to AAR programs. The FRA also sponsored the conference, and other groups are involved in rail-related transportation research.

The TRB study recognized research needs in the following categories: the condition of rail transport, problems external to the industry, and problems internal to the industry. Plant and equipment, which loom so large in the AAR budget, is one of eight research categories on internal problems; operations is another.

The differences between the AAR research and test program and the recommendations from the TRB study are easy to explain. The TRB study observes that earnings are too low for the industry to achieve its full potential and that there is a resurgence of interest in revitalizing rail transport. The AAR research program represents historical and institutional views of research needs; the TRB study represents needs by considering transportation activities as a whole. The two views are quite different. Unfortunately, as the railroad industry is structured, it is difficult to see how innovations and innovative paths can be created that would be responsive to the broad research agenda put forward by TRB. Given its structure, what the industry is able to do is better represented by the AAR research and test agenda.

About one-quarter of the AAR budget is spent on operations and another quarter on interactions between guideways and vehicles. A partial explanation for the work on operations was put forward before: The railroads are operating entities. A further explanation seems to lie in those same conditions that provided the climate for the TRB report: the widespread recognition that productivity must be increased. Although competition within the regulated industry is dampened, railroads have lost competitive ground to other modes, thus the high priority of research on operations.

The priority given to research and test work on guideway interaction represents an attempt to repair a neglected problem. Equipment and guideway decisions have been made independently for too long. Current shortages of funds for guideway maintenance and the railroads' use of larger, heavier cars have forced a crisis. The high priority given to the rail-car interaction problem is the reaction to this crisis. One industry spokeman dates the problem from the early 1960s (19). Another has remarked that "there has not been enough cooperative discussion between the equipment engineer and the track engineer" (20), a condition we take to be the norm, which supports our observation about disjointedness.

Technology Sharing

DOT is transferring the results of federal research, development, and demonstration efforts to meet regional, state, and local needs (21). DiLuzio and Albin have analyzed DOT mechanisms and programs for technology sharing (22). The Transportation Systems Center maintains a program office and provides general support for DOT. Each modal agency operates its own program, and the Office of the Secretary handles matters outside the scopes of the modal agencies (for example, pipeline safety). The DOT program is linked to counterpart agencies at the state and local level.

Is there any need for a technology-sharing program? A high level of interaction and integration within the components of transportation already exists. Furthermore, because the professionals within components belong to the same professional groups, well-developed methods of communication already exist. Technology sharing may simply duplicate existing technology-transfer pathways. Indeed, the list of mechanisms and programs for technology sharing is mainly a list of things that are already being done (21, 22). Not unexpectedly, the needs expressed for technology represent a listing of the concerns of actors within technological components; responses differ only slightly, depending on whether the institution is a state transportation department, a regional organization, or that of a local municipality (22).

DOT technology sharing may be contrasted with the view of technology and technology transfer expressed by the work of the Stanford Research Institute under contract to the Technology Utilization Office of NASA. This work is commercial path and product oriented. The study team "realized that the problem-originating public-sector agency usually benefits from the technological solution only when a commercial product reached the market place" (23). The study begins with the ensemble of problem solutions that NASA has developed. These solutions are matched in some way to problems recognizable in transportation activities. Therefore, a thermoplastic material for binding rocket propellants has been put forward to improve road-patching materials, and a material developed for supersonic-transport brakes has been suggested for improving the brakes on rail cars and postal vehicles. These are examples from 10 technology transfers claimed by the study team.

This work represents only one of several technology strategies used by NASA. For example, a different strategy is represented by the extensive technological and market-analysis work done in connection with NASA short takeoff and landing aircraft programs, and another strategy is represented by NASA's long-standing relations with the aerospace industry.

Another research and development and technology transfer strategy is discussed in work recently completed for DOE (24). This work reviewed 12 major federal research and development efforts and studied the innovation process in the public and private sectors. The primary result was the proposal of a technology implementation planning (TIP) process that is currently under consideration for implementation by DOE. The key idea underlying the TIP process is that issues of implementation ought to be considered at every step in formulation of research and development strategies; decisions about research and development strategies ought to be made in terms of downstream implementation.

In a TIP analysis, the description of the desired technology merges with the question of how the product or process will be diffused. A work program and research plan then follow with regard for the diffusion process. Implementation milestones are identified, and the relaxation of barriers to implementation is considered. Thus, the research and work plans cover both innovation and implementation, and decisions with respect to resource requirements, milestones, and work to be done all are included in the total technology-transfer process. A trial TIP has been worked out for a Stirling engine (25). The TIP process is not to be confused with technology assessment; rather, it is an aid to management and program development. Technology transfer surely has assessment components, yet the primary focus is elsewhere.

Comparisons of the DOT technology-sharing program, the NASA technology-sharing activities, and the TIP process proposed for the DOE are in order. The DOT strategy may be viewed as the strengthening of within-component technology transfer. We have asked whether it is necessary, since there are extant component linkages. The NASA strategy may be seen as a shotgun commercialization strategy. A vast resource is claimed to exist in NASA problem solutions. The NASA strategy filters these solutions by identifying uses for transportation and opportunities for commercialization. We may also ask if the NASA process is needed. Entrepreneurs exist in the private sector who screen possibilities and chase profits. In the presence of an existing mechanism, why create another?

The rebuttal to our questions about DOE- and NASA-technology transfer is that these are workable processes that can be made to work better: Within-component technology transfer works; private-sector technology transfer works. Technology-transfer programs represent efforts to make those processes work better, and their working better is surely desirable.

We can pose useful questions about TIP in the following way: What if TIP were applied to the NASA commercialization process (for components)? what if TIP were applied to the DOT within-component process? Diffusion mechanisms are strong in these two processes. Is the application of TIP necessary and can anything be learned from it? Suppose the process were applied to the needs identified by the TRB study of railroad research. We cannot guess the outcomes of these applications completely, but the TIP process would most likely identify as diffusible those research and test programs in which the industry is already engaged. A lack of diffusion, barriers, and a low payoff under present institutional and regulatory environments would probably limit management's interest in research and development to extant work.

CONCLUSIONS

We have characterized the supply and demand aspects of transportation technology. Needs are vast when they are broadly expressed as improvements in the functions or roles that transportation performs or might perform in society. Most commonly, however, needs are expressed in terms of reduced costs or of service responsiveness. The supply process is constrained by its disjointed, incremental properties. Individual component supply streams perform well, but there is little or no consideration of technology systems. These characteristics limit the effectiveness of rail technology programs and technology-transfer activities.

By extension of this finding to all transportation technology, the adequacy of supply processes is adversely affected by limitations in our thinking about transportation.

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