Dual Mode: Automating High-Cost Urban Transportation Rights-of-Way

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This paper attempts to outline the case for dual-mode transportation systems as the candidate urban transportation system most responsive by far to the entire range of current and foreseeable issues and values governing transportation investments in urban areas. The paper first outlines these issues and describes the resulting criteria that alternately propel and impede the implementation of alternative urban transportation improvements. Analysis reveals that dual-mode transportation systems respond logically and affirmatively to all criteria. Fractional-second headway. automated electrically powered guideway systems capable of accommodating a variety of vehicle sizes, and vehicles capable of manual operation off the guideway are indicated. The vehicles would serve both public and private transportation needs through a much larger variety of ownership, pricing, and service schemes than available today. Relative to conventional internal combustion engines, electric power would allow flexibility in the use of basic energy sources, control of air pollution from power generation at relatively few sources, and precise longitudinal control of vehicle location and spacing on the guideway. Conclusions are drawn on the appropriate role and resulting performance requirements for dual-mode transportation systems.

Urban transportation improvements can significantly reduce the cost of urban travel to users and society. Innovation in transportation and elsewhere changes established practice or design. The innovation concluded here as significantly reducing both user and social costs of transportation requires changes in the technology of producing urban transportation. The change is no small incremental change but one that includes automating the driver function over large parts of urban travel and providing flexibility in the basic energy sources used in urban transportation.

Urban transportation in the United States and throughout the world is in a state of crisis, and so are cities. Our available transportation technology confronts us with Hobson's choices in the form of more of the same highway and transit "solutions." New urban expressways that represent the intrusion of rural highway solutions into high-density urban areas are stopped by controversy in practically every major city (1). The deficits for urban transit systems are skyrocketing, and only higher fares or controls on private use and not more kilometers of track will lower these deficits. There are no easy off-the-shelf alternatives to satisfy the demands that something be done now to significantly improve urban transportation. Innovation is required to significantly lower the cost of urban travel to users and society.

Today in U.S. urban areas, the private automobile carries more than 95 percent of all person trips (2). Since 1920, the trend has been toward increasing use of private transportation to serve urban passenger travel. The urban transportation system that exists in the United States today has reached its present state largely as the result of an evolutionary process. The system was not planned in any formal, integrated, long-range manner. Rather, the highway and transit components serving urban personal travel have developed independently from one another, as have many of their subsystems.

Until recently, government action in urban transportation has been largely in response to real or perceived changes in market demand for the service offered by each transportation subsystem. Government intervention has been limited to aiding growth in the case of the private automobile-highway system or to stimulating in the case of urban public transportation. But the logic of past actions no longer matches present national concerns. We have an energy "problem," and the cutting edge of that problem is the real, or at least clearly perceived, shortage of domestic oil. It is fair to say that, in the United States, transportation is a technology built on the use of oil. Oil is currently the basic source of 97 percent of the energy used in transportation in the United States (3). In 1965, 57 percent of the oil used in the United States was used in the transportation sector, and 54 percent of that oil was used in urban areas (4), a share that can be expected to grow as urban areas grow in population.

When these energy consumption statistics are combined with air pollution statistics that attribute 40 to 90 percent of air pollutants in urban areas, depending on type, to motor vehicles, the pressures on government to reduce private motor vehicle travel in response to these nonmarket criteria become understandable (5).

It is significant that both the energy shortage and the air quality concerns of the country are externalities whose real costs to individuals and to the country as a whole are not reflected in the costs that consumers of private vehicle transportation pay. Until this country adopts gasoline rationing, it is marketplace prices that influence the demand for private transportation.

THREE STAGES OF INNOVATION

As the perceived cost of transportation to urban consumers has declined in the last half century, cities have spread out, resulting in declines in manufacturing costs and increases in space and privacy for most urban residents (6, 7). Cities are definitely into what Garrison calls the third stage of innovation as it relates to the private car (8).

The first stage of innovation typically occurs when an invention performs an existing function better or more efficiently than the function was previously performed. The early motor car was faster and pulled more weight (on dry roads) than the horse. But its function was the same as that of the horse. In the second stage of innovation, money is spent to make the invention perform more competently. The innovation is improved and its use is diffused. New uses are found for it. In the case of the motor car, self-starters were developed, vehicles were adapted for moving goods as well as people, and chauffeurs were added for urban motor bus transit. The third stage of innovation occurs when the structure of the system, in this case, the city, adapts in such a way that the innovation is able to perform at still lower cost and increasing gain to individuals.

Urban areas are well into the third stage of innovation as it applies to the motor car. The structure of urban areas has changed in a way that allows the automobile to operate more effectively and fixed-route and scheduled transit service less effectively! The radial transit routes of 30 or 50 years ago no longer serve the bulk of travel patterns in today's cities.

The success of the automobile in servicing urban transportation brings problems traceable to its high consumption, and these problems lead to much of the use of other forms of transportation. The overwhelming remaining market for transit is in the central business districts of major cities where "overconsumption" of the automobile leads to high parking charges and traffic congestion characteristic of the high equilibrium price that users of private vehicle transportation pay for "free" movement and that CBD-bound travelers avoid by using public transportation. Other travelers, including the poor, the elderly, the young, and the handicapped who have no access to a car for either CBD and non-CBD trips, must also be served by "logical" urban transportation system improvements.

IMPROVING URBAN TRANSPORTATION

To some, urban transportation improvements solve not transportation or mobility problems but urban development problems (9). However, there is no agreement on urban development goals, so recommendations for urban transportation in accordance with such goals are based on great uncertainty. One alternative, therefore, is to proceed incrementally to attack little transportation bottlenecks. This is essentially what is happening today in cities. A second alternative is to closely examine all criteria governing current urban transportation investment decisions to determine whether there is a transportation system or a series of compatible subsystems, existing or potential, capable of lowering the travel costs that are perceived by transportation consumers and the nonmarket (social) costs of urban transportation that have been given great weight by recent congressional actions.

FIRST STAGE OF INNOVATION

Because cities are so well into the third stage of innovation today, a logical, innovative urban transportation system capable of serving cities must recognize what the present travel market consists of and how it is being serviced. We have noted that the first stage of innovation is successfully hurdled when an invention performs a function better than it has been performed before. And the great bulk of the existing urban transportation function is currently being performed completely flexibly in time and space by the private automobile.

One might assume that some public agency could provide transportation service in an urban area cheaper than individuals could and still earn a profit, particularly in urban areas where there are overlapping desire lines in time and space for part but not all of those trips. If there were complete overlapping of individuals' travel needs, the fixed-route and scheduled service of urban transit could serve as a perfect link between all origins and destinations at the times when such trips were desired. Transit would not have its present severe underconsumption problem.

Unfortunately, fixed-route and scheduled transit service does not overlap all the origins and destinations in time and space that characterize present urban travel. For example, in 1963, about 11 percent of trips in the Greater Boston Region were made in whole or part on its relatively well-developed rail transit system (10). This market share has declined still further since 1963. The 11 percent who found it to their advantage to use rail transit in that year averaged only about 40 percent of their total door-to-door travel time in the rail transit vehicle. The remaining 60 percent of their time was spent getting to and from the rail transit stations. Research has shown that these "access activities" are about 2 to 3 times as noxious to travelers on a unit time basis as line-haul riding time (11, 12). On a weighted basis, this means that from 75 to 80 percent of a rail transit rider's time is spent making his or her way to and from the primary mode of travel. For those who ride in automobiles (90 percent of the trips in the Boston region are made by automobile), only about 10 percent of door-to-door travel time on the average can be considered out-of-vehicle or access time. If new transportation systems are not to become functionally obsolete before they begin service, they must be designed to reduce walks and waits in absolute and uncertainty terms.

These statistics illustrate the great disparity that now exists between public and private transportation service in urban areas. To successfully hurdle the first stage of innovation, an urban transportation innovation must consider how users view the system. It must concern itself with what drives consumer behavior in urban transportation if it is to reduce the cost of urban travel to users and society.

On the other hand, there is a legitimate public point of view dictated by logic (and sanity) in the design of a transportation innovation. If we are going to reduce the symptoms of the urban transportation problem that our unmatched private mobility brings—space consumption, air pollution, and energy costs—we must specify for transportation innovation the performance and technological requirements that lower each of these societal costs of transportation. These requirements must lead to a transportation system that is a logical and compatible collection of components or subsystems. The task is not difficult.

DUAL-MODE URBAN TRANSPORTATION

Reduction of space consumption requires reduction of the physical and the socially perceived cross section of urban transportation facilities, in particular expressways, the facilities that provide the highest quality transportation service. This means reducing the time spacings between moving small vehicles and their space consumption when stopped. This requires automation of the driver function: automated operation at short headways (time spacings between vehicles) on automated guideways. However, we will always be limited by economic reasons in automating the line-haul portion of trips, just as we are limited today for economic reasons alone, in kilometers of planned expressways. Automation of the driver function will always be limited to those areas in which total costs, including social costs, need to be reduced. The easiest way to provide the door-to-door transportation service enjoyed today for the great bulk of urban trips would be to build on the means by which we provide that service today, namely, manually driven vehicles. Thus, we have the primary specification of the logical urban transportation innovation, namely, that it be dual mode. Dual-mode systems are combinations of two system technologies: automated guideway and nonguideway systems using the same vehicle or passenger "pod."

ELECTRIC POWER

If dual-mode systems satisfy the convenience requirement for urban transportation innovation, how can these systems be designed to reduce the social costs of urban transportation that are driving society in the first place to make radical changes in the way urban transportation is supplied? In particular, if automated guideways can reduce space consumption, how can they be made to reduce air pollution and energy consumption? The most obvious answer involves electric power. Electrically powered small vehicles allow much closer and more precise headway control than can be achieved with the internal combustion engine. But more important, electric power allows conversion of basic energy sources like hydrocarbons to electric energy at a few remote sites where pollution control devices can be installed and maintained. There are more than 118 million motor vehicles running around the United States today whose pollutants we are attempting to control individually. Moreover, use of electrical energy allows a substitutability of basic energy sources and can introduce a flexibility into transportation energy use patterns that has been largely absent since the 1920s for urban personal transportation.

Off the electrically powered automated guideways, there might again be flexibility in the on-board energy source. Most likely, however, dual motors would not be attractive, and the electric motors would be powered by batteries. The batteries would be recharged on the guideways and at parking places to provide power for the remainder of the vehicle trips under manual control on local uncongested streets.

GUIDEWAY CAPACITY, SPEED, AND SPACING

In urban planning terms, the automated portions of dual-mode systems can be thought of as automated expressways carrying a mix of vehicles at 96 km/h (60 mph) and at expressway capacities. Initial studies that take into account the additional induced travel from congestion-free operation at expressway speeds and the incorporation of line-haul transit service on the guideways indicate a guideway requirement of approximately twice the length of that for planned (but often unbuilt) urban expressways (i.e., half the spacing for expressways) plus additional guideways equal to the length of that of the existing grade-separated transit system in a city (13). This requirement also takes into account the accommodation of induced travel resulting from the improved coverage of a city with high-quality service, line-haul guideways.

In contrast to planned urban expressways, automated guideways should be buildable. Instead of having eight 3.6-m (12-ft) lanes plus shoulders, medians, and drainage areas and taking a 60 or 90-m (200 or 300-ft) swath across the city, they would require two 1.8-m (6-ft) lanes, since lateral as well as longitudinal control results with automation. Such a narrow cross section could be completely enclosed, soundproofed, buried, put through buildings, or have other possibilities for minimizing dislocation and disruption.

NEEDED RESEARCH AND DEVELOPMENT FOCUS: FRACTIONAL-SECOND HEADWAYS

To equal the capacity of an eight-lane expressway in each direction, a single guideway would have to carry four times as many vehicles per hour as present expressway lanes carry. With roughly 2-s average minimum headways between manually controlled cars on current expressways, this means 0.5-s headways between automatically controlled vehicles on the guideway. How to achieve safe, reliable fractional-second headway control is the major technological problem to be overcome in innovating a transportation system improvement that reduces the cost of urban travel to both users and society and, thus, has the potential of being built.

Fractional-second headway operation of small vehicles on automated guideways can be achieved today. The problem is to design such systems to operate safely and reliably under day-to-day operating conditions in cities. These systems must be far safer than today's urban highways because users will identify any accident on the system with the entire guideway system rather than blame accidents on an elusive "other" driver who is out of sight and mind. The technological problem does not, however, appear to be insurmountable, as development efforts outside the United States indicate (15):

Hagen, West Germany—Team of MBB and Demag engineers began operation of a 160-meter (526-foot) test track with one station in May 1973. This is high-capacity PRT system with headways in the range of 0.5 to 1.0 second at 22 mpg. Vehicles have seating capacity for three people. System is expected to be installed for passenger service in 1976.

Japan—300-meter (988-foot) test track operating since October 1972, and 4.7-km (2.9-mile) track with 90 four-passenger vehicles scheduled to begin full-scale test in December 1973. System under development by eight Japanese firms under contract with Japanese government. High-capacity (0.6-second headway) system has speeds from 20 to 40 mph and is expected to begin passenger service in 1975.

In addition to efforts at electronic control of vehicle spacing, other concepts are possible, such as mechanical fail-safe linkages and systems that maintain such short spacings between vehicles that shock-absorbing bumpers could cushion any collisions that would occur at low relative speeds.

CONCERN FOR TRANSIT

Transit, with only 5 percent of urban travel, still looms large in the public consciousness as an important mover of people—so large that most of the federal effort in urban transportation innovation is lodged in the Urban Mass Transportation Administration. It is axiomatic in attitude measurement that the rated importance of an item varies inversely with the level of satisfaction achieved with the item. This may partly explain the relatively high interest in transit.

The fractional-second headway requirement for significant urban transportation innovation results not only from the requirement of serving the bulk of existing urban travel (i.e., highway travel) but also from a requirement of being buildable.

Transit now offers fixed-route and scheduled service on limited networks. Personal rapid transit (PRT), the most important emerging technology in urban transit, attempts to overcome the time limitation by offering small-vehicle, nonstop operation available instantly, but limited to the fixed and automated network. There are at least three major differences in concept between "pure" PRT and conventional transit.

1. PRT's off-line stations means the PRT vehicles need not wait for stopped vehicles at intermediate on-line stations (i.e., PRT is a flow system);
2. PRT stations can be close together since not all vehicles must stop (this gives better coverage of an area than does conventional transit, at additional expense for the additional stations, of course); and
3. Small, personalized vehicles available at each station require no wait, in concept, and seats are available to all comers.

Thus, PRT in concept offers considerable service improvement over conventional transit. However, a problem with having a vehicle ready to board on demand for a trip to some distant destination is that the vehicle has low average occupancy. Vehicle occupancy estimates from "pure" PRT planning studies based on no data are approximately 1.5 persons/vehicle. In reality, this may overstate PRT vehicle occupancy relative to the automobile. Vehicle occupancies greater than 1.0 in private cars (varies between 1.1 and 1.8 persons/vehicle with urban trip purpose) may be attributed to familial groups starting from home in a car and sharing common destinations or to prearranged car pools that pick up riders door to door with some waiting and intermediate stopping required. In a large PRT network the probability of arriving at a station at exactly the same time as someone else going to the same distant station is low. In any event, based on the 1.5 persons/PRT vehicle, to carry 10 000 persons/h in a medium-sized city (the upper range of so-called intermediate capacity transit, and a long held minimum volume for conventional rail rapid transit) requires (3600 s/h × 1.5 passengers/vehicle × 1 h/10 000 passengers =) 0.54 s/vehicle. Again a headway of approximately 0.5 s is required!

The shortest headways that manufacturers are willing to install on PRT automated guideways range around 10 s for 38 to 80-km/h (30 to 50-mph) systems (the so-called safe stopping time or "brick-wall" headway, assuming a safe emergency deceleration rate of 0.2 *g*). Since present systems are not yet capable of operating at fractional-second headways, the only way to increase passenger throughput in PRT systems is to increase vehicle occupancy. The vehicle occupancy required to achieve 10 000 passengers/h at 10-s headways is (10 000 passengers/h × 10 s/vehicle × 1 h/3600 s =) 28 passengers/vehicle. This means PRT vehicles must be held at a station until 28 passengers board going to one destination station or going to several stations, or passengers may be picked up at several stations destined to one or more stations. Holding a vehicle at one station to accumulate passengers involves waits. Shorter waits can be obtained for the same vehicle occupancy by stopping at more stations, but this strategy decreases average speeds and makes the operation more closely resemble conventional transit.

The generally proposed operating plan for PRT is a compromise strategy. This "impure" PRT, perhaps better called group rapid transit (GRT) (15) has stops at each of a block of adjacent stations to pick up passengers and then runs express to a destination group or block of stations. The run is regularly scheduled, ideally with relatively short waiting times (60 to 180 s). For large systems, so many destination stations would have to be served that initial waits for any destination station or block of stations could easily be longer than those for conventional rail transit making all intermediate stops, if 10-s headways were maintained. However, GRT's flexibility could ensure that high-volume stations or blocks received superior service.

REDUCING THE COSTS OF INNOVATIVE TRANSIT

The advantages of GRT over conventional transit are, in concept, somewhat fewer stops, shorter waits, and possibly higher average travel speeds, but these apply mainly for smaller systems and only if available technologies are "pushed." PRT, pure or impure, may excel over conventional transit in guideway coverage. Increased guideway coverage would make walking time to and from the guideways less than that now available or "feasible" with conventional rail systems.

PRT planning reports seem to abound in which guideway networks are so dense that they might be mistaken for the local street system of a small city. The question is, Why should PRT or GRT guideway systems be any cheaper than conventional rail transit networks? Can the cost per kilometer of automated guideway systems be made much less than that of conventional rail systems in order to build all the guideway proposed in some PRT planning studies?

We can legitimately ask the question, Where are the savings in PRT cost over that of conventional transit? Not in command and control systems. Possibly in power distribution with untrained vehicles and thus smaller surges of power when vehicles accelerate. However, there will be more vehicles and thus probably higher costs in the vehicle subsystem. Right-of-way costs may be less, but only if the guideway cross section is much slimmer and easier to locate on existing publicly owned rights-of-way.

The real cost savings of PRT over conventional transit are alleged to be in the structure. This is most likely true for light 2 to 6-passenger vehicles. But for the 28-passenger vehicles required now without fractional-second headways, the vehicle weight and the vehicle cross sections are not substantially less than those for conventional transit vehicles. Expensive structures are needed, or PRT tunnels equally as expensive as rapid transit tunnels.

In summary, there appear to be no substantial cost savings with existing PRT (really GRT) technology over conventional grade-separated transit. For the same number of kilometers of guideway at roughly the same direct and social cost as electrified rapid transit (barring unforeseen difficulties with a new technology), a city can now buy almost off the shelf a group rapid transit system that has off-line stations and that offers comparable, but potentially somewhat superior, service to that of a conventional rapid transit system of the same length. However, service overlaps well in time and space only with a small fraction of total travel in an urban region. True PRT is based on personalized vehicle service and fractional-second headways. Without fractional-second headways, passengers must be assembled to boost line-haul capacity, service is degraded, and system costs are increased. Fractional-second headways are again indicated as the major technological focus, this time from a more narrow production orientation, namely, a concern for transit.

SUMMARY AND CONCLUSIONS

Significant improvements in urban transportation service require short headway systems. From the point of view of transit, fractional-second headways are the only way to lighten transit vehicles and reduce structure size and costs—both direct costs and the social costs of large guideway structures. Similar concerns apply to urban highway systems.

In summary, the logical innovation in urban transportation, both public and private, consists of fractional-second headway, automated guideway systems, and vehicles capable of dual-mode operation. These would be integrated systems serving both public and private transportation needs.

As the title of this paper suggests, dual-mode transportation means automating high-cost urban transportation rights-of-way. The fractional-second headway, automated guideways would provide the high-quality and reliable line-haul express service for private vehicles that present expressways provide under the best of conditions. The private vehicles would be capable of dual-mode operation. That is, they would be capable of automated operation on the guideway and operation under manual control on local streets to provide the door-to-door service that the great bulk of urban travel enjoys today, and around which metropolitan areas are structured.

For public transportation, riders could be carried on vehicles captive to a network. That is what transit is today; the additional feature is that the new service is either scheduled service or service on demand. The service would overlap in time, if not in space, with many travel demands in an urban region. The more extensive guideway network needed for dual-mode, private vehicle operation would provide improved coverage of a city over today's grade-separated transit networks. Moreover, to obtain even more coverage, dual-mode buses could leave the automated rights-of-way.

Electric power allows flexibility in the use of basic energy sources, and control of air pollution at a relatively few sources.

The recurring argument that a transportation system should provide a "choice" needs addressing in this context. The argument is made that cars are noxious, and many people do not own or cannot drive them. An entirely different mode is therefore to be provided for non-car people according to the argument. However, an integrative transportation system would provide for several classes of service, all of which would be substantial improvements over today's choices. Indeed, an integrated system should provide for choice in the most optimistic sense of the word as used today!

Automation is clearly a central theme in this paper, as well as in most other efforts to increase productivity in commercial and military systems. But only large jumps in system productivity allow the built-in redundancies and down time that characterize even the most successful uses of computers today. Such increases in productivity are possible in urban transportation only with fractional-second headways. Achieving safe and reliable fractional-second headway operation, therefore, is the central technological problem on which this country should be focusing urban transportation innovation.

Technological change can come about for different reasons. A few years ago, in the face of the urban expressway controversies, dual-mode guideway systems with fractional-second headways appeared to be the only way to provide new transportation capacity at low social cost (16). It may now be that the benefits of dual mode in improved transportation system performance are secondary to its provision of low polluting, alternate energy sources for urban transportation. But urban transportation should solve both problems; it should reduce both user and social costs of transportation. Recent history shows how fickle society is in its values and in the problems it produces.

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