vices through increased levels of activity and increased pools of potential employees. This impact will be skewed so that positive benefits will accrue to activities previously poorly served by transportation (they will become more accessible) and decreasing benefits will be associated with previously well-served activities (their relative advantage is decreased by the new service). The extent of this impact will depend on the number of users of the new service.

TOTAL EVALUATION

The total evaluation of demand-responsive services is, as previously discussed, a local process, and the factors entering the process and their relative weights will vary greatly. However, several factors now evident must be considered in the evaluation of a proposed system.

1. As previously determined in research and now confirmed by operation, there are increasing economies of scale in DRT ride operation. This in itself can be an argument for providing subsidized operation. Specifically, more productive operations can be provided at higher demand densities; however, to achieve higher demand densities requires subsidy.
2. Even in subsidized DRT services to date, demand densities have been in the range of 2 to 10 passengers/mile^2/hour. At these demand densities, to expect productivities of greater than 5 to 7 passenger trips/vehicle/hour is unreasonable.
3. If it were possible to increase demand density to the 20 to 30 passenger/mile^2/hour range, productivities in the 9 to 12 range are achievable. But the service provided must be made more attractive; subsidization alone will not suffice.

Jerry D. Ward, Office of Research and Development Policy, U.S. Department of Transportation

This paper briefly reviews some of the development trends in cities and their implications for urban transportation systems. The conclusion is one we already know well: The CBD-focused, fixed-route transit systems common today are badly mismatched to the evolving needs of increasingly low-density and multinucleated cities. The principal significance of flexible-route systems such as DRT is that they have been the missing element that lets this mismatch be overcome, permitting us to think in new terms about public transit systems. Regionwide door-to-door systems such as we are beginning to see in Orange and Santa Clara Counties, in Rochester, and in Ann Arbor are the leading edge of this trend. For the first time since Henry Ford, it may not be ridiculous to think in terms of modal splits of 30 to 50 percent of all nonwalking person trips rather than 3 to 5 percent.

The second part of the paper presents some conjectures as to how these regionwide systems might evolve. The conclusion is that, although the flexible-route elements are what make these new systems possible, the major growth is likely to be in proliferation of the fixed-route structure.

The promise of these new systems is great, and success in bringing about a major shift to transit could be of substantial importance to the nation, but it is not going to be easy. We know little about these systems and the public reaction to the kinds of service we think they can offer. In my opinion, the next 5 years are the critical ones for the future of urban transportation.

REGIONWIDE, DOOR-TO-DOOR SYSTEMS

The purpose of this brief discussion, which is more fully developed in another report

(1), is primarily to emphasize that DRT or flexible-route systems are being looked at not as special-market or neighborhood systems but as enabling elements of regionwide integrated systems consisting of both flexible-route and fixed-route elements. It is intended to ensure that we are all talking about the same thing.

Terminology can be a problem. I use the term "flexible-route systems" to encompass the whole gamut: automobiles, van, or minibuses operating in either the telephone-responsive, prearranged (subscription) mode or the street-hail mode. It includes single-passenger taxis at one end of the service scale and many-to-many demand-responsive minibuses at the other. One may prefer the term paratransit (which also includes fixed-route jitney), but the basic rationale being developed is not altered.

Figure 2 shows a typical transit system. It is primarily CBD oriented, whereas less and less travel is. The service in the suburbs is poor or nonexistent. If it is available, it never seems to go where it is needed and its service frequency is low. Roughly half of the population now live in these suburbs.

The problem is economics. Good fixed-route service implies close headways and route spacing. At low ridership density, this means most buses run empty or nearly so. Good service with fixed-route systems is just not affordable in low-density suburbs.

Every morning almost half of the nation's trips start in the suburbs, and they start in a car because there is not an adequate alternative available. The consequence is too many cars downtown, along arterials, and in suburban high-density developments.

The car, if one is available, is superb in trips that are confined to low-density areas; but in high-density areas where land is at a real premium, it takes up too much space. (Its energy and pollution problems are curable—at a price.) The bus and rail that are much more space efficient are poor at the low-density end of the trip. If congestion is to be cured, the car must be kept out of high-density areas. The options to do so are (a) park-and-ride, which requires parking facilities and 2 cars; (b) kiss-and-ride, which requires free labor; and (c) flexible-route system, which requires subsidization.

Each option has its place, and all should be encouraged. Except for the few DRT systems in place, the taxi is the only flexible-route system available, but it (in common with any unsubsidized system) is too expensive to attract the level of ridership for which we should strive. The subsidy issue for both privately and publicly owned systems is discussed more fully later.

We might appropriately also list as an option controls on car usage—car management—because it is likely to be an important and necessary element in system design. This alone is not enough unless the alternative transportation service offered in its stead is reasonably good.

The obvious answer is a mix of systems, acting cooperatively. These are schematically shown in Figure 3, which depicts an expanded fixed-route network forming the backbone of the high-density service and variants of flexible-route elements serving the lower density suburbs. The alternative of park-and-ride is also offered.

The phrase "acting cooperatively" should be stressed. It does not imply necessarily common ownership of all elements, nor should the service offered in any particular neighborhood be restricted to a single kind of system element. A neighborhood or area may have many kinds of different transportation needs, and a mix of system variants within that area may be appropriate.

SYSTEM EVOLUTION

It is not precisely clear what we mean by a successful system. Some criteria for success are

1. Double current transit ridership,
2. Achieve full decongested traffic flow without car disincentives,
3. Achieve mostly decongested flow with some car disincentives,
4. Increase current transit ridership 10 times, and
5. Provide 99 percent availability in time and space.

Figure 2. Typical transit today.

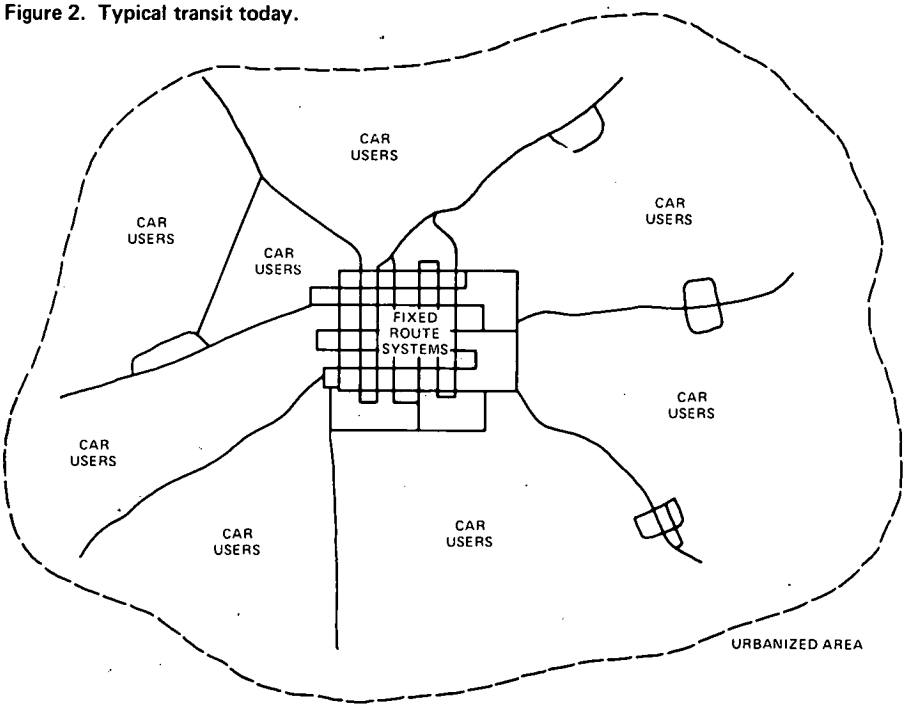
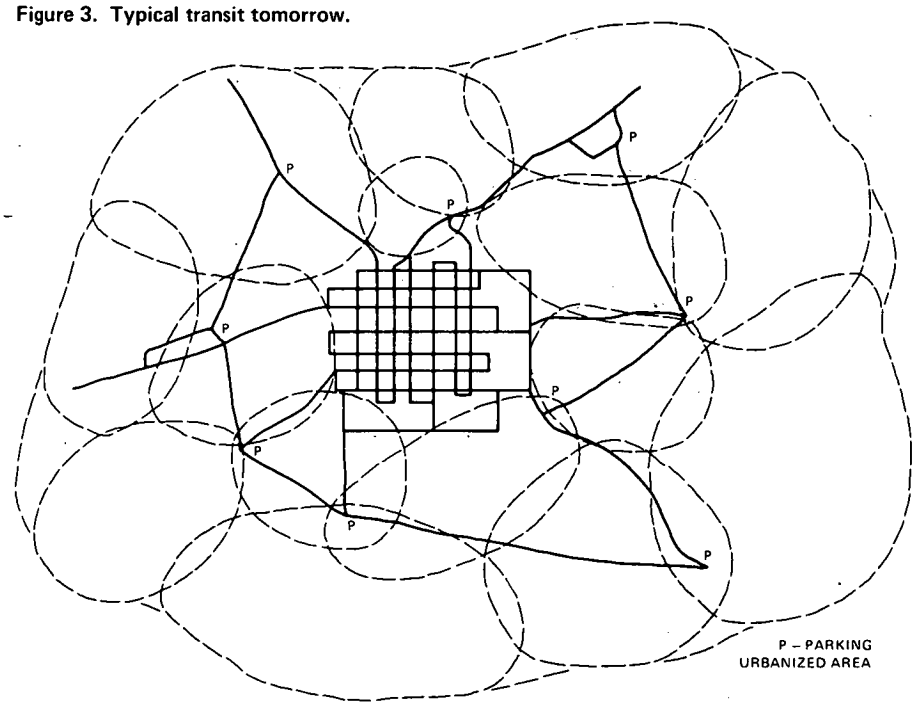


Figure 3. Typical transit tomorrow.



To double transit ridership is not enough to affect congestion and energy problems; we start from too small a base. Criterion 5 implies a system that serves essentially all the urbanized area and provides at least some kind of service on a 24-hour basis. If we try to do this without getting a much more dramatic increase in ridership than just doubling, poor economics would ultimately doom the system.

Criterion 2 expects too much. These new systems are clearly more attractive "carrots" than we are used to, but some "stick" to control automobile usage will be needed. To wean people from automobiles is hard. Criteria 3, 4, and 5 recognize that substantial improvement in public systems will require some car disincentives and restrictions on their usage, that we are aiming at much larger modal splits than we normally think in terms of, and that the suburban nondriver will finally have a good alternative to staying home.

I have no basis other than natural optimism for thinking these criteria are realistic. I am unaware of any in-depth work to estimate the service and cost characteristics of the multielement, integrated systems at large modal splits—the supply side of the problem. The demand side of estimating ridership for various carrot-stick combinations is almost pure guesswork.

We are not used to thinking about how these systems would behave at large modal splits. In the following, some thoughts on this subject are developed, and their implications for how the system might evolve are inferred. At least some of the impact of increased ridership implies either better service or lower costs with system growth: shorter wait times, more direct routes, and more express fixed-route service.

Figure 4 shows a comparison of a flexible-route system and a fixed-route system offering the same level of service, defined as the ratio of walk, wait, and trip time to the best no-wait direct route. (There is no walk or wait time for the flexible-route system, but the route is circuitous.) This figure, based on data developed in another report (2), is presented here to be illustrative, not definitive. At lower ridership densities, fixed-route bus is much more expensive than flexible-route bus, but the situation reverses as ridership climbs. Even though flexible-route systems are the cheapest way to supply service at low ridership density, such service is still more expensive than high-density service.

Figure 5 adds similar curves for an improved level of service. The principal point is that the range of ridership density where flexible routing is preferred is extended. Thus, at a given ridership density, the curves imply that flexible-route elements become, at some service level, preferred to fixed route. Thus, the higher the service level is, the greater the proportion is of flexible-route elements in the total system. Not surprisingly, better service costs more money.

In a total regionwide system, there is a distribution of ridership densities that range from low in sparse suburbs to high in downtown areas and in high-density suburban complexes. If the various elements that make up the total system are optimally tailored to the desired level of service at the ridership that exists at that time, every system will be a mix of different variants of fixed- and flexible-route elements.

Figure 6 shows raising the level of service will increase flexible-route elements in proportion to fixed-route elements. Off-peak, the distribution of ridership densities that represent the system shifts to the left, so that more flexible-route elements are appropriate. As the system grows, the distribution moves to the right, lowering costs and adding more fixed-route elements. As ridership density increases, more vehicles are needed to serve the flexible elements, and more flexible-route vehicles are also added; but the dominant growth is in fixed-route elements.

Figure 7 expands on the point that these systems should adapt their modes of operation with the time of day. Since systems are sized largely by peak-capacity requirements and off-peak costs are essentially fixed costs, almost any revenue generated off-peak is marginal income. Thus, a high level of off-peak service is affordable and desirable at well below what might be called its instantaneous cost.

Work-hour staggering is a trade-off. It hurts car pooling and helps transit. According to a U.S. Transportation Systems Center analysis, staggering is net benefit from a purely transportation cost point of view. It obviously has commercial and other impacts that need to be considered.

Figure 4. Fixed-route and flexible-route trade-off at the same level of service.

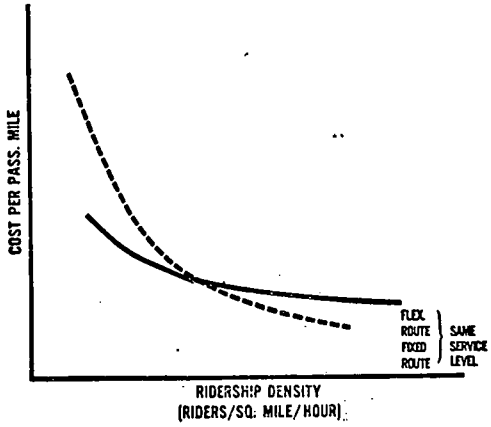


Figure 5. Fixed-route and flexible-route trade-off at improved level of service.

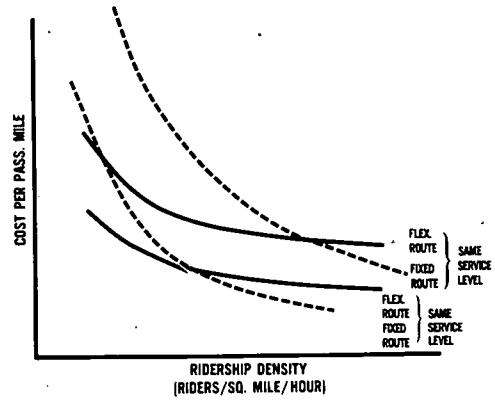
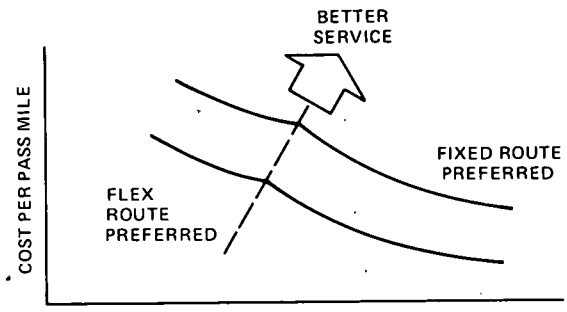
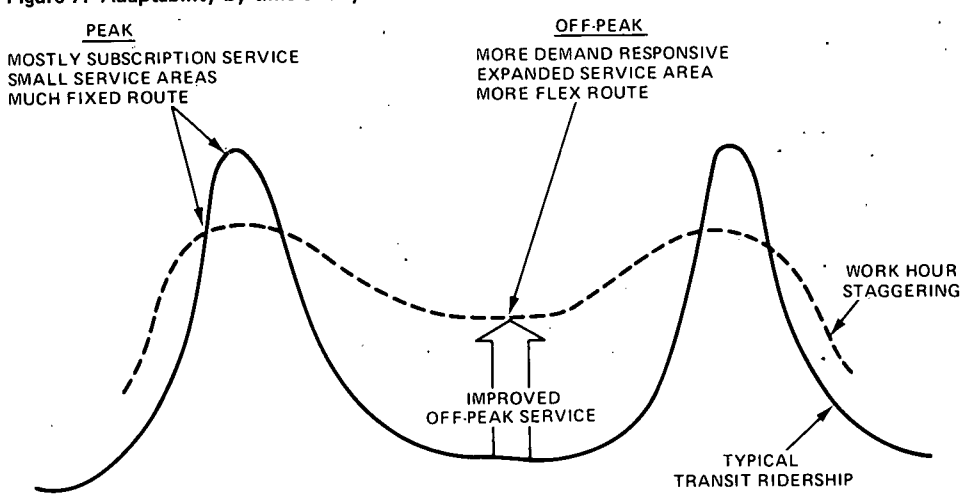


Figure 6. Summary of fixed-route and flexible-route trade-off.



- FOR A GIVEN RIDERSHIP DENSITY, BETTER SERVICE MEANS HIGHER COSTS, MORE FLEX ROUTE IN PROPORTION TO FIXED ROUTE.
- FOR A GIVEN SERVICE LEVEL, GROWING RIDERSHIP MEANS LOWER COSTS/PASS MILE, MORE FIXED ROUTE ELEMENTS
  - OFF-PEAK: MORE FLEX ROUTE
  - GROWTH OVER TIME ADDS MORE FIXED ROUTE ELEMENTS

Figure 7. Adaptability by time of day.



The evolution of these systems over time is shown in Figure 8. The first phase is that in which coverage of the low-density suburbs is being added. The second is the growth phase after complete coverage has been achieved. These two phases are discussed in turn.

The new flexible-route elements that are added to evolve from a limited-coverage, fixed-route system to an integrated, full-coverage system have higher costs and lower productivity than the already existing fixed-route elements (Fig. 6). Figure 9 shows that, without overall ridership growth or better peak and off-peak use or both, average costs per passenger will rise. This occurs at the same time as a multitude of new management problems are being experienced. This initial expansion phase is most critical: Public attitudes are still largely unconverted, car ownership habits are unchanged, management and operators are pioneering innovation, and the overall concept is unproved. It may require a lot of faith on the part of the supporting authorities to survive misjudgments that are easy to make with the relative lack of experience with such systems, particularly if costs per passenger are rising. It would appear to be important to select initial flexible-route elements where the opportunities for good ridership response are greatest.

Figure 10 shows the next phase of growth. We have assumed success: The system is in place. Now growth provides the opportunity for incremental improvements and proliferation. The central point is that growth now occurs not primarily by expansion of flexible-route elements (although some may be added in high-density areas as supplements to fixed-route elements). Many special point-to-point express elements could become feasible, offering a high level of continual service between high- and medium-density activity centers. These are all high-productivity elements, so now system economics improve on a per trip basis.

This is an important conclusion because, if it is correct, it implies that the vehicle management problem may not be so formidable as often depicted and that ridership growth leads to continually better service and more flexibility of choice, encouraging still further growth. At some point in growth, marked improvements in congestion should begin to appear. Success should breed success.

The overall problem of cost allocation and fare pricing is beyond the scope of this paper, but the subject of subsidy for the flexible-route elements should be mentioned. Experience to date suggests that these new elements cannot be expected to pay for themselves and still attract the much higher level of use we are trying to encourage. Passing over, for the moment, the problem of an appropriate level of overall subsidy, there should be an internal-to-the-system cross subsidy between high- and low-productivity elements. If there is a single fare for the total trip, then this is accomplished.

There is no inherent reason why private taxi operators could not attract substantially more business and offer more variant service if they are not constrained to price their services to cover costs. If it is accepted that subsidy to the flexible-route service in low-density areas is necessary to make the whole system work, then the possibility of paying that subsidy to a private operator should be carefully considered. This is a complex subject that must be equitably handled to prevent public subsidy from competing unfairly with private capital.

These systems lend themselves ideally to incremental planning and implementation. Origin-destination patterns are determined by the system, so adapting the system to changing demand is straightforward: They almost plan themselves.

Although Figure 10 suggests a rosy picture, there are several sticky unknowns, as shown in Figure 11. When the decision is made to initiate expansion of coverage by adding the higher cost flexible-route elements, it is a gamble as to whether overall costs per passenger will rise or whether ridership increases and better peak and off-peak matching will compensate. Assuming the system survives this phase and further growth brings down average costs per passenger, the total deficit will still rise as shown. Whether it is realistic to think these costs will decline sufficiently for the overall system to pay for itself is an open question.

Figure 8. System evolution.

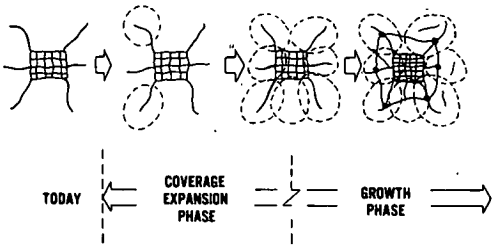
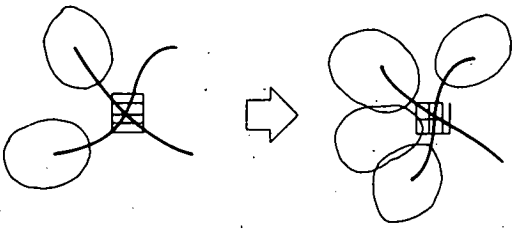
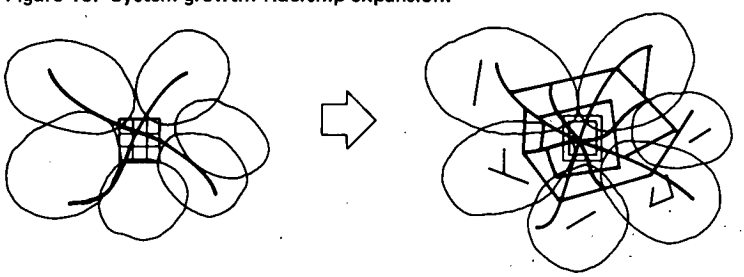


Figure 9. System growth: coverage expansion.



- ADDING LOWER PRODUCTIVITY FLEX ROUTE ELEMENTS: $/PASS MILE RISE
- MAY BE BALANCED BY BETTER OFF-PEAK UTILIZATION, HIGHER OVERALL RIDERSHIP
- MANAGEMENT/CONTROL PROBLEMS GROW FASTER THAN RIDERSHIP

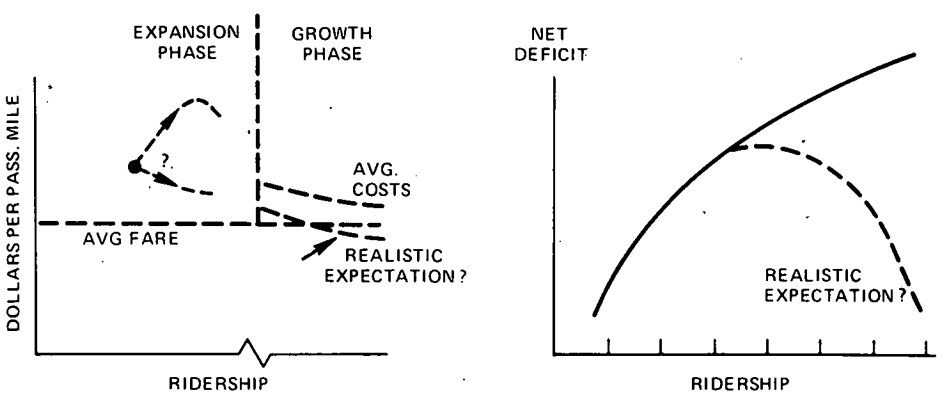
Figure 10. System growth: ridership expansion.



- ADDING HIGHER PRODUCTIVITY FIXED ROUTE ELEMENTS: $/PASS MILE DECREASE
- OVERHEAD AMENITY COSTS (TRANSFER FACILITIES, INFO SYSTEMS) SMALLER PERCENT OF PASS MILE COSTS
- MANAGEMENT/CONTROL PROBLEMS MAY GET EASIER: MORE MANAGEMENT OVERHEAD AFFORDABLE, NUMBER FLEX ROUTE VEHICLES GROW SLOWLY, NEW FIXED ROUTES PLAN THEMSELVES.

Figure 11. The problems.

- ABSOLUTE COSTS MAY LOOM LARGER AND LARGER IN LOCAL BUDGETS



- PUBLIC ACCEPTANCE ? (WHAT SIZE INCENTIVE ?)

CONCLUSIONS

The promise of these kinds of systems is substantial, and it is hard to identify acceptable alternatives. The major points are

1. DRT (flexible-route) systems permit a different concept of public transit—service that is door-to-door, almost indoor, and regionwide, if major patronage can be attracted; and
2. If successful, it could be a national decongestant, provide mobility for the nondriver, contribute to energy conservation, lead to fewer multicar families, and create lots of jobs.

The desirability of fewer multicar families and labor-intensive systems lies, like beauty, in the eyes of the beholder. I suspect even the automobile makers would not take violent issue with the overall desirability of better public transportation and fewer cars downtown, even though it is probably a net decrease in vehicle investment. It will happen slowly and may well result in desirable side effects.

Labor intensiveness may not be all bad, except that it clearly makes the systems vulnerable to labor disruption. Although the trend is still embryonic, from the national view labor is increasingly becoming a fixed cost. Systems that require only moderate capital (which will continue in short supply) and provide socially desirable, important, and productive jobs may be a plus for the nation's economy.

The DRT concept was the starting point. If we can put it all together and make these regionwide systems really happen, it would be of truly significant national importance.

REFERENCES

1. J. Ward and N. G. Paulhus, Jr. Suburbanization and Its Implications for Urban Transportation Systems. Office of the Secretary, U.S. Department of Transportation, April 1974.
2. D. Ward. A Theoretical Comparison of Fixed Route Bus and Subscription Bus Feeder Service in Low Density Areas. Applications Division, Transportation Systems Center, Cambridge, Mass., June 1974.

Panel Discussion

Before the general discussion, Daniel Roos, session chairman, asked a panel to comment on several prepared questions. Panel members were Richard V. Gallagher, International Taxicab Association; Karl W. Guenther, Ann Arbor Transportation Authority; Jerry D. Ward, U.S. Department of Transportation; Nigel H. M. Wilson, Massachusetts Institute of Technology; and Eldon W. Ziegler, Urban Mass Transportation Administration.

DANIEL ROOS: What comments do you have on the evaluation process?

KARL GUENTHER: I wish I had written Jerry Ward's paper because he said some things that some of us have been trying to say for a long time. He pulled concepts together that needed to be pulled together. In our local DRT operation, our evaluation comes once a year at our annual budget time. Each year as we sit down to decide how much service we are going to give, how much it is going to cost, and what our annual deficit is going to be, we go through this evaluation process.

ELDON ZIEGLER: To evaluate the transit system, we are seeking some rough