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DUAL-MODE TRANSPORTATION: A CASE STUDY OF MILWAUKEE

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A socioeconomic case study analysis of the Milwaukee metropolitan area, in which a hypothetical dual-mode transit system was compared with a modern, conventional bus rapid transit plan designed to meet the area's needs as forecast to 1990, showed the dual-mode transit concept to be an attractive alternative offering many significant advantages. It was concluded that dual-mode transit systems offer significantly higher service quality (ability to attract riders), higher labor productivity, competitive fares, benefits exceeding costs, greater attainment of regional development goals and objectives, a high degree of operational flexibility to meet varying transportation needs, and, possibly most important, growth potential with good cause to expect a long-term trend of increasing utilization, increasing total benefits, and increasing economic operating margins. It was also concluded that other medium-to-large metropolitan areas nationwide may enjoy even greater relative benefits from this technology.

•THE Milwaukee County Dual-Mode Systems Study was conducted under a $300,000 study grant issued to Milwaukee County by the U.S. Department of Transportation, Urban Mass Transportation Administration. The study was initiated in January 1971 and completed 12 months later. The overall study objective was, in brief, to assess the merit of the dual-mode concept from a socioeconomic viewpoint, to assess its technical implementation feasibility in terms of presently available technology, and to specify an initial centerline plan for dual-mode implementation.

The overall study effort consisted of three major activities: a technical evaluation, a socioeconomic evaluation, and a dual-mode transit demonstration planning effort corresponding to the study objectives. These areas of activity are documented in three separate volumes and a summary report (17). The basic approach to the socioeconomic evaluation of dual-mode transit, the subject of this paper, has been to use a comparative analysis method, contrasting the performance, cost, benefits, and regional goal attainment factors associated with a hypothetical dual-mode system with those of a modern bus rapid transit plan. The referenced bus rapid transit system is representative of the most cost-effective application of conventional bus technology possible for Milwaukee. It is currently being considered for implementation as a result of the recommendations made in the Milwaukee County Mass Transit Technical Planning Study, a three-year effort completed in June 1971 under a $500,000 local, state, and federal jointly funded study grant (1).

DUAL-MODE CONCEPT DEFINITION

Dual-mode as a transportation concept has many facets. The dual-mode concept has been proposed in widely varying contexts over the last decade—large public transit buses (Metromode), private vehicles (Urbmobile, StaRRcar), palleted automated transport (PAT), public automobile rental (PARS), and others—depending on the application objective as perceived by the designer. These diverse potential applications are illustrative of the potential of dual-mode for fulfilling many different urban transportation needs (2, 8, 10, 12, 14-16).

In simplest terms, dual-mode is defined as a guideway-vehicle system that permits two modes of vehicle operation: fully automatic (driverless) operation on a specially equipped guideway and manual (driver-controlled) operation in mixed traffic in the normal manner on conventional roadbeds. The varied applications each have in common this unique characteristic of dual-mode—vehicle operation both on and off an automated guideway. The dual-mode concept thus embodies what may be termed the "customary" benefits of an automated captive-vehicle transportation system while still retaining the flexibility of the conventional street vehicle—free to operate over any street, independent of the availability of special guideway facilities.

Among the various alternatives for the initial implementation of a dual-mode system—transit vehicles, private vehicles, automated pallets, special service vehicles, and public rental vehicles—transit appears to be the logical mechanism for the introduction of dual-mode technology into the urban community. A detailed discussion of the merits of transit as an initial dual-mode demonstration is presented in Volume 4 in the overall report series (17) and also is summarized briefly in the following:

1. At the present time the technology required for a dual-mode transit system (which requires a guideway of relatively low capacity) is available, and a system of rather limited scope would, in itself, possess a high degree of utility.
2. In addition, a relatively high ratio of user benefits to costs could be achieved in early transit applications.
3. An added advantage of transit over private vehicles for initial dual-mode implementation is the fact that the system operator retains a high degree of control over the transit vehicle, thereby ensuring that proper maintenance is enforced and that critical control devices are not subject to tampering.

Consequently, the socioeconomic case study analysis discussed in the succeeding paragraphs treats primarily the benefits associated with an initial dual-mode transit system, featuring relatively small (19-passenger) dual-mode transit buses—probably the first stage of dual-mode evolution. However, in addition, a preliminary estimate of the additional benefits achieved when a dual-mode guideway system is made available to the private dual-mode vehicle user is also presented.

SOCIOECONOMIC EVALUATION: STUDY APPROACH

A case study approach was used for the socioeconomic evaluation of a hypothetical dual-mode transit system, with the Milwaukee metropolitan area providing a "real world" data base for the analysis. As a result of other comprehensive regional and local planning studies, the Milwaukee area offered a wealth of demographic, economic, land use, and transportation data that were used in the case study, permitting the performance, benefits, regional goal attainment, and cost characteristics of a dual-mode transit system to be contrasted with a conventional modern bus rapid transit plan (1). This reference system represents the most cost-effective transit system application for Milwaukee that is possible with currently available bus or rail transport technology.

Two major studies that were used extensively in the case study are the Milwaukee County Mass Transit Technical Planning Study and the Southeastern Wisconsin Regional Planning Commission (SEWRPC) Land Use-Transportation Plan for 1990 (1, 11). In essence, the SEWRPC regional land use-transportation plan, the result of an extensive 4-year study completed in 1966, set forth alternative land use development patterns, corresponding transportation demand forecasts, and supporting transportation system plans for the Southeastern Wisconsin region projected to the year 1990. The recommended plan cited the need for Milwaukee County to begin assessing alternative means of implementing a rapid transit system that would meet the travel demands forecast within the region for 1990, while effecting a better balance between highway and transit use.

As a result, Milwaukee County, under a $500,000 study grant awarded in 1968, initiated the Mass Transit Technical Planning Study, which was completed in June 1971. After considering many possible transit system alternatives, the conclusion of the study was that a modern bus rapid transit system would be best suited for the area's needs, particularly in view of the changing travel patterns, the highly dispersed, low-density character of new land use development, and the need to ensure a flexible system plan.

This proposed new transit system for Milwaukee, referred to subsequently as the rapid transit plan or the conventional bus rapid transit system, was used as a comparative reference for the socioeconomic case study analysis.

The case study evaluation included consideration of transport demand (ridership), service levels (or system performance), transport-related benefits and costs, and attainment of regional development objectives. The results and conclusions of each of these areas of analysis are summarized here. Volume 3 of the report series contains the analysis method, assumptions, and more detailed results.

The general approach to the analysis has been to (a) establish performance objectives for the dual-mode transit system; (b) simulate the performance and loading of a 1990 dual-mode network, using the comprehensive transit-highway regional planning models and recommended future land use pattern available at SEWRPC; (c) determine capital and operating costs for the system, based on the hardware design concept definition developed in Volume 2; and (d) combine these cost-performance-demand data in an analytical framework consistent with that used for the conventional bus rapid transit plan so that a meaningful comparative analysis could be performed.

The basic premise on which the case study was based is that the dual-mode transit concept should be oriented toward providing the highest quality transit service possible in order to ensure that an increased number of "choice" riders would be attracted to the system. The study indeed indicated that this could be achieved and would result in higher benefits as well as higher, but justified, costs. This high quality of service operating strategy led to the definition of a relatively large, 110-mile guideway network, a relatively small dual-mode transit vehicle, and close operating headways, features that may not be an appropriate strategy in all urban situations.

Thus, a second facet was introduced into the case study, consisting of a preliminary sensitivity analysis that considered variations in vehicle size, choice of service characteristics, network scope, and alternative operating strategies. This analysis served to illustrate the broad spectrum of alternatives that could characterize any given dual-mode transit system configuration and operating strategy, depending on the objectives to be achieved. This high degree of flexibility, offering options not open to conventional systems, may well be the greatest asset of this novel transportation concept.

The effect on transit system costs and fares due to the incorporation of private dual-mode vehicles within the system, subsequently referred to as the mixed vehicle system, was also examined. This analysis illustrated the economic merit of a unique aspect of the dual-mode concept—the potential for use of the guideway facility (and right-of-way) not only by transit vehicles but also by properly equipped private automobiles and other commercial vehicles. Some of the more significant results of these analyses are presented in this paper, without discussion of assumptions and method, which are contained in the Volume 3 report (17).

The remainder of this paper is organized into four parts. First, the dual-mode and reference conventional bus rapid transit systems used in the case study are described. Next, the case study comparative analysis results, based on simulation data obtained from the regional models and cost-operating data obtained from the technical evaluation (Volume 2), are presented. Third, a summary of the results of the cost-performance sensitivity analysis and an assessment of the economic impact of the private dual-mode vehicle on the transit system are given. The paper is concluded with a summary of overall findings and conclusions.

DESCRIPTION OF THE MILWAUKEE CASE STUDY SYSTEM

Geographical Region

The geographical scope of the case study system was chosen to be the metropolitan Milwaukee transit service area as identified by the 1990 rapid transit plan. This transit service area centers on the City of Milwaukee, is bounded by Lake Michigan on the east, and includes the urban, suburban, and urbanizing fringe areas to the north, south, and west of the city, covering a rectangular area measuring approximately 12 by 24 miles. According to the regional plan, a total population of 1,850,000 is forecast within the transit service area by 1990, generating an average daily travel demand of 4,050,000 internal person trips, as contrasted with the estimated 1970 population of 1,350,000 and an average daily travel demand of 2,900,000 internal person trips.

Study Time Frame

The year 1990 was chosen for the case study for two important reasons. First, the conventional rapid transit plan, while staged for initial implementation in the mid-to-late 1970's, was designed to serve the 1990 land use pattern of the service area and by 1990 may be expected to provide its "full-scale" service characteristics and benefits. Second, and possibly most important, the rapid transit plan is entirely compatible with the dual-mode transit concept so that it conceivably could evolve by 1990, in part or completely, to a dual-mode system. Thus, it was logical to investigate the relative cost-performance-benefits-goal attainment characteristics of the two systems under the 1990 conditions.

It is important to recognize that, as noted earlier, dual-mode transit is only one aspect of the dual-mode concept. Therefore, even under 1990 conditions, the dual-mode system reflects attractive benefits that are only in an infancy stage, whereas the conventional bus rapid transit plan illustrates benefits that are represented in their full maturity, and in all likelihood represent the maximum benefits attainable within the confines of conventional bus system technology. The importance of this factor, intangible though it may seem, should not be underestimated.

System Description

The rapid transit plan recommended in the Milwaukee County Mass Transit Technical Planning Study is based on the use of modern, gas turbine-powered, 53-passenger transit buses (similar to the General Motors RTX prototype), which operate primarily on existing streets and freeways, providing efficient and rapid point-to-point line-haul service. In the most heavily congested transportation corridor, the east-west freeway (Interstate 94), a transitway approximately 8 miles in length, was recommended for the exclusive use of rapid transit vehicles. It was further recommended that the transitway and vehicle design have provision for automatic lateral steering control, in order to minimize the width of the right-of-way required for the transitway. Although the rapid transit plan system promises to provide attractive and efficient line-haul service, a limitation in its service features for many potential users lies in the fact that it does not include neighborhood collection-distribution operation in most cases. Rather, it relies primarily on the availability of an auto for park-ride or kiss-ride or on the use of local feeder buses to provide access to rapid transit stations.

The dual-mode transit system is also based on a rubber-tired transit vehicle, but of considerably smaller size, approximately 19-passenger capacity (all seated). The dual-mode system, rather than operating solely on existing streets and freeways, operates primarily on an exclusive transitway or guideway under fully automatic (driverless) control. The exception to guideway operation is, of course, the manual operation mode under driver control on arterial streets, where the dual-mode system, again in contrast to the rapid transit system, offers neighborhood collection-distribution service, providing virtually door-to-door, no-transfer transit availability.

Both systems are based on a fixed schedule-fixed route operation concept. However, the dual-mode system inherently has the growth potential of evolving to a demand-actuated, dynamically routed system, which is likely to be less practical under the conventional bus rapid transit plan.

A summary of operating and physical characteristics differentiating the two systems is given in Table 1.

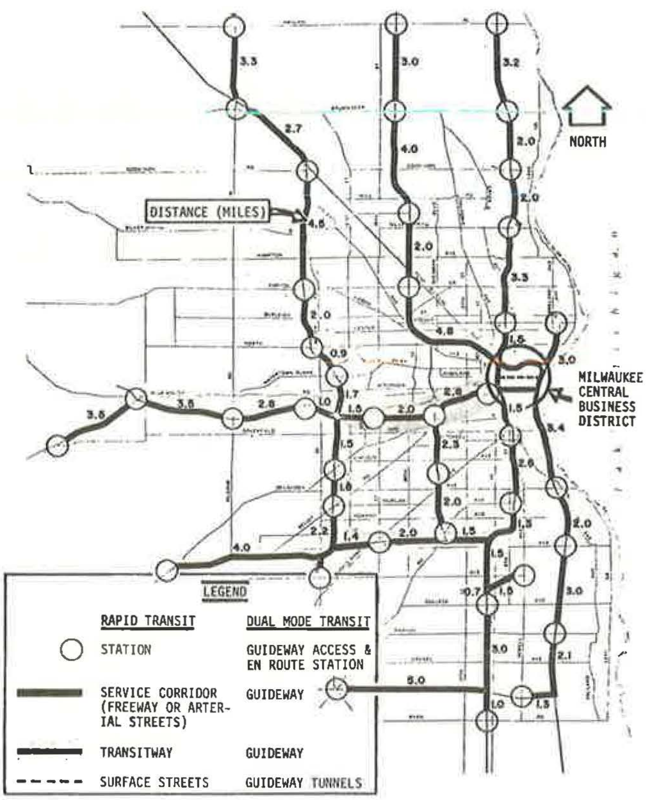
The major service corridors for the rapid transit plan, including the locations of main-line stations, are shown in Figure 1. Figure 1 also illustrates the 110-mile guideway network which, after careful deliberation, was chosen to overlay identically the same transportation service corridors as were originally identified by the regional plan and subsequently refined in the technical transit planning study. The circles in Figure 1 indicate the rapid transit station stops and also illustrate the points of access and departure for dual-mode vehicles to and from the guideway system.

Table 1. Comparison of dual-mode and rapid transit system characteristics.

Characteristic	Conventional Bus Rapid Transit	Dual-Mode Transit
1. Operating Concept		
Operating mode	Manually operated on existing freeways	Automatic operation on exclusive guideways, manual operation on local streets
Operating strategy	Fixed route, fixed schedule, point-to-point service	Fixed route, fixed schedule, door-to-door service
Operating headways during peak hour (min)	5	5
Number of routes	40	264
Maximum main-line speed (mph)	60-70	60-70
2. Vehicle Description		
Propulsion type	Gas turbine	Electric drive
Vehicle passenger capacity	53	19
3. Configuration		
Vehicles required	381	2,585[1]
Number of guideway (transitway) miles	8	110
Number of major park-ride lots	37	5[2]
Number of main-line stations[3]	40	40
Number of neighborhood pickup and destination distribution points off the main line	100 (approx.)[4]	3,500 (approx.)
Primary mode of access to system	Via park-ride	Via neighborhood pickup

[1] Required to service a ridership level estimated to be approximately double that of the rapid transit plan.
[2] Selected park-ride facilities would be provided at a few undetermined locations.
[3] Located at the guideway or along the rapid transit route.
[4] Several rapid transit routes would include limited neighborhood pickup service.

Figure 1. Service corridors for the dual-mode and rapid transit systems.



Guideway/Transitway Facilities

The exclusive transitway proposed in the rapid transit plan is also shown in Figure 1. Also shown, for the dual-mode transit system, are the two guideway tunnels necessary to serve the central business district. In order to better characterize the nature of the 110-mile guideway network, preliminary estimates of the distribution of right-of-way requirements by real estate type, and the type of guideway construction envisioned, were made. It should be observed that almost 80 percent of the required guideway mileage can possibly be aligned within available rights-of-way in freeway corridors, railroads, or on vacant land. Most of the guideway facility (about 75 percent) can be constructed essentially at grade or in open cuts, with appropriate grade separations, rather than requiring a more costly underground or elevated approach.

MILWAUKEE CASE STUDY EVALUATION: RESULTS AND CONCLUSIONS

In this section, a comparative evaluation of the conventional bus rapid transit system and the dual-mode transit system is presented. The evaluation is based on the dual-mode network simulation results obtained from application of the SEWRPC transportation simulation models, the dual-mode system costs as determined by the system definition study, and the aforementioned local and regional planning studies. The evaluation is presented under four discussion topics: transit service, transport-related benefits, regional goal attainment, and system operating and capital costs.

Transit Service Characteristics

The transit service characteristics of the dual-mode system, as contrasted with the conventional bus rapid transit plan, are described in terms of demand, system accessibility, and trip characteristics.

Demand for Transit Service—The demand for dual-mode transit service, obtained from a simplified mode split forecasting procedure, is summarized in Table 2, which shows a projected ridership level for the dual-mode system that is approximately double that of the conventional system. The apparent reasons for this significant increase in ridership will be described shortly. In brief, however, the dual-mode transit system provides a significantly higher quality of service such that former automobile users are likely to be attracted to transit.

These ridership projections are, of course, highly dependent on the assumptions employed in the mode choice model, and therefore projections for any new system must be viewed cautiously. The marketplace provides the only true test of ridership attraction for such a new system. It was not the purpose of this study to explore the many subtleties of mode choice, so the ridership forecast is regarded as preliminary.

The mode choice model employed was based on locally determined travel time diversion data (transit/auto travel time ratios) used in the regional planning studies and on an additional multiplying factor, assumed to be a linear function of trip length, intended to reflect additional ridership attraction due to the unusual comfort-convenience features of the dual-mode system. In brief, it was assumed that seating for all, arrival-time certainty, and reduced transfers would together be at least half again as important as travel time for longer transit trips, but of relatively little significance for shorter trips. These factors, taken collectively, are thought to be treated conservatively (9) so that the ridership levels forecast by the simulation are judged to be reasonable.

Accessibility to Transit Service—As mentioned previously, both systems provide transit service to the same geographic area, but the route resolution provided by each system—that is, the typical distance the average commuter must travel to have access to the conventional rapid transit or dual-mode bus—is much different. The dual-mode transit system provides considerably greater accessibility and availability than the conventional bus alternative. This result may be attributed to the following three factors:

1. The conventional bus rapid transit system does not provide extensive collection-distribution service. It assumes that an auto or local feeder bus will be available to transport most would-be transit riders to the nearest rapid transit station. This assumption, of course, is not always tenable, and its transfer requirements are undoubtedly

a factor in the decline of transit ridership nationwide. It is a necessary assumption, however, for a transit system based on a large (53-passenger) bus, because that type of vehicle cannot efficiently serve the entire service area surrounding each station in a collection mode. Even if it could, the time required to fill the bus by stopping at many low-demand, scattered neighborhood stops would undoubtedly be viewed negatively by most commuters.

2. It is an inherent feature of the dual-mode transit concept that rapid transit service can extend beyond the main-line, heavily traveled corridor by leaving the guideway network, reverting to manual operation under driver control, and proceeding into dispersed neighborhood areas to provide virtually door-to-door neighborhood collection-distribution service. This service becomes practical not only because of the dual-mode capability of the vehicle but because of its relatively small size, permitting many more neighborhood routes to be provided. The relatively small vehicle size is significantly related to the dual-mode concept in that, as will be shown later, the economic benefit of automated (driverless) guideway operation provides a significant increase in system productivity, because the driver pool is focused only on collection-distribution service, with the line-haul function being provided under fully automatic control. The simulation indicated that vehicles traveled on the guideway network (no driver cost) approximately 70 percent of their operating time.

3. Because of the lesser dual-mode vehicle passenger capacity (approximately one-third of the conventional rapid transit bus, in this case), the dual-mode transit system requires almost three times as many vehicles in order to service the same peak-hour travel demand. As noted previously (Table 2), however, the demand for dual-mode service slightly more than doubled. As a result, during the 1990 morning rush hour in Milwaukee, the dual-mode system would have 2,585 vehicles in service, whereas the conventional rapid transit bus system would require only 381 vehicles. Thus, the dual-mode system has the potential of offering almost seven times (2,585/381) as many routes or, alternatively, providing seven times the frequency of service on a given system of routes during the peak hour. As presented earlier in Table 1, the dual-mode system offered 264 routes, whereas the conventional bus rapid transit system provided 40.

In summary, the dual-mode transit system provides greater availability and accessibility because, in contrast to the conventional bus rapid transit plan, the dual-mode system provides collection-distribution service and at the same time also has more vehicles operating on more routes.

Trip Distance and Speed—The average transit trip distance, travel time, and speed during the peak hour are shown in Figure 2. It can be seen that the dual-mode transit system has about a 10 percent shorter trip time for an equivalent trip distance, but that travel time comparisons vary for different trip components (collection, line-haul, distribution). Note also that the travel distribution pattern changed on the dual-mode system, for reasons that will be discussed subsequently, resulting in a longer average transit trip length.

Average trip speed is also shown in Figure 2. This does not represent vehicle speed, but rather door-to-door travel time, including walk and wait times as well as on-board vehicle time. For the case study conditions, the average walking distance on a dual-mode route to a neighborhood dual-mode stop was assumed to be less than one-quarter mile, and an average wait time, during the peak hour, was assumed to be 2.5 minutes. It can be observed from Figure 2 that the speed advantage of the dual-mode trip is also about 10 percent.

It should be noted, however, that the average trip speed on the conventional bus rapid transit system is primarily dependent on the availability of an automobile for a portion of the trip. (If the rapid transit system is served by local feeder bus—not the case for most forecast trips in Milwaukee—the total transit trip time is further increased by about 11 minutes, in which case the dual-mode transit shows a 30 percent speed advantage.) It should also be noted from Figure 2 that the dual-mode system has the potential of continually improving average trip speed consistent with technological advances. In contrast, it appears likely that the conventional bus rapid transit system can only decline in performance as freeway traffic densities increase, unless an investment is made in more miles of exclusive transitway.

Thus, the trend of the conventional bus rapid transit system appears likely to be one of either decreasing performance or increasing cost. On the contrary, as will be seen subsequently, the dual-mode transit system is more likely to exhibit an increasing performance trend with decreasing costs.

Trip Distribution—Although the dual-mode transit system showed an average trip time savings during the peak hour of less than 10 percent, the typical time saved ranged from 3 percent to 17 percent, depending on the trip destination. Figure 3 shows the distribution of peak-hour trips by destination category and the corresponding trip time reduction offered by the dual-mode system.

Transfer Requirements—Another important characteristic of the average transit trip is the number of transfers required to arrive at the desired destination. If fewer transfers are required, increased comfort, convenience, and reliability of travel can be expected. Figure 4 shows a significant reduction in the number of transfers required in the dual-mode system. Note particularly that 94 percent of the commuters boarding the conventional bus rapid transit system require a transfer from either their auto or a local feeder bus. The remaining 6 percent of rapid transit riders live within walking distance of a rapid transit station. The dual-mode transit system required considerably fewer origin transfers—only 21 percent. Overall, the rapid transit plan required an average of 1.2 transfers per trip whereas dual-mode transit required only 0.5 transfer per trip (and only 0.3 transfer for an equivalent distance average trip).

Comfort and Convenience Factors—There are several important differences in the comfort and convenience aspects of the two systems. These are intangible factors, but nonetheless are significant, as indicated by consumer preference surveys (9). The following are some of the considerations:

1. Comfort—The vehicle interior comfort features of both systems are likely to be the same; however, the dual-mode system offers a comfort advantage on two accounts. First, and most important, as previously discussed, the availability of a one-seat, no-transfer ride is a significant comfort and convenience advantage. Second, the ride quality associated with automatic control on the guideway is likely to be more comfortable because of congestion-free, virtually constant-speed travel.
2. Reliability of service—The certainty of the transit system consistently achieving scheduled pickup times and corresponding trip completion times is likely to be higher in the dual-mode system as compared with the conventional bus rapid transit system. This potential for high reliability of service is attributed to the exclusive guideway concept and the system automatic control concept that is based on the maintenance of a rigorous, precise operating schedule.
3. Convenience—Certainly the dual-mode system offers a higher degree of convenience for most transit riders because of its door-to-door, essentially no-transfer service and also because of its greater availability due to the larger number of routes and vehicles.

Transport-Related Benefits

The annual user benefits that relate directly to transportation—travel time savings, avoidance of accident costs, avoidance of private vehicle operating and parking costs—are shown in Figure 5 for both systems. The methods and assumptions employed are presented in more detail in Volume 3 of the report (17). The significant factor to be noted is the relative difference between the two systems, rather than the absolute dollar benefits. Note particularly that the annual savings in the value of travel time accrued to the highway user in the case of the dual-mode system is greater than the corresponding savings to the dual-mode transit user. This is the result of a significant reduction in freeway peak-hour volume (approximately 14 percent) and a corresponding increase in average freeway speeds. This is a particularly important benefit because it increases the effective useful lifetime of existing freeway systems.

Similarly, there are user costs associated with any transportation system. These annual user costs are illustrated in Figure 6. The relatively high travel-time loss

Table 2. Peak-hour travel characteristics.

Peak-Hour Characteristic	Rapid Transit Plan	Dual-Mode Transit	Growth Factor
Person trips	31,237	61,605	2.0
Vehicle-miles	16,503	70,615	6.7
Vehicle-hours	381	2,585	6.8
Driver-hours	381	784	2.1
Driver-hours per vehicle-mile	0.036	0.011	0.3

Figure 2. Transit trip lengths and speeds for the dual-mode and rapid transit systems.

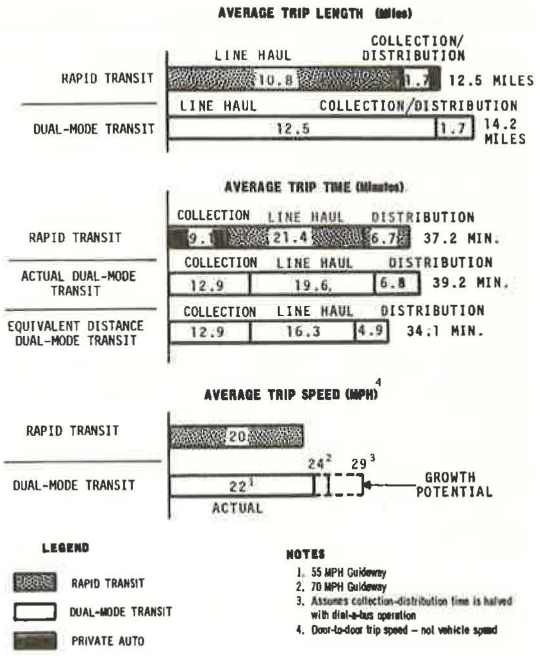
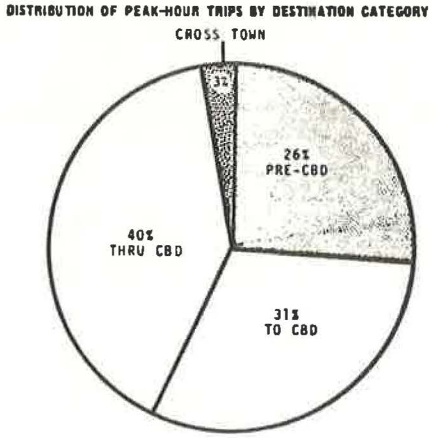


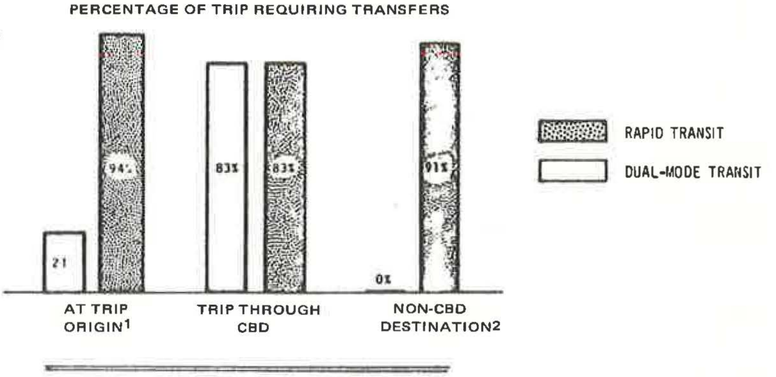
Figure 3. Distribution of peak-hour trips and dual-mode trip time savings relative to the rapid transit system.



DUAL-MODE TRIP TIME REDUCTION BY DESTINATION CATEGORY

TRIP TYPE	DUAL-MODE TRANSIT TRIP TIME REDUCTION (%)
PRE-CBD	13%
TO CBD	3%
THRU CBD	17%
CROSS TOWN	14%

Figure 4. Comparison of transfer requirements for the dual-mode and rapid transit systems.



NOTES:

1. Most rapid transit trips originate via park-ride or local bus trips to the transit station, whereas most dual-mode trips originate on neighborhood pickup routes.

2. Non-CBD destinations are reached via the dual-mode system by direct crosstown service or by one transfer in the CBD. The rapid transit system typically requires two transfers—one in the CBD and the second to a local feeder bus distribution system in the vicinity of the ultimate destination.

associated with the dual-mode system is attributed to the so-called choice rider—one who has other alternatives available but chooses transit. Most choice riders will actually lose time via dual-mode or rapid transit as compared to the travel time they would achieve via automobile. Unless congestion levels on freeways are inordinately high, which is not the case in Milwaukee, travel characteristics by private automobile generally represent an exceptionally high standard for a transit system to compete with. Thus, these travel time "losses" are not unexpected.

It is seen from Figures 5 and 6 that the dual-mode transit system offers significantly higher transport-related benefits as compared with the conventional bus rapid transit plan. The costs, however, are also higher. But in both cases the benefits exceed costs.

It is concluded, then, that the dual-mode transit system, although capable of offering greater benefits, also has proportionately greater costs. This should be viewed, however, with the perspective that the dual-mode transit transport benefits will represent only a portion of total potential transportation benefits. As discussed later, when the dual-mode guideway system begins to accommodate other vehicle types—further increasing system revenue and further reducing existing freeway loadings—overall community benefits are likely to continue to increase.

As will be seen in the succeeding section, the quantifiable transport benefits of a transportation system are by themselves an inadequate basis for determining the relative merit of competing systems. Urban planners are becoming increasingly cognizant of the need to also address broader regional goals and objectives.

Regional Goal Attainment

The degree to which both case study transit systems meet the regional transportation objectives and supporting standards, as identified by SEWRPC in their regional land use and transportation planning study, is given in Table 3. It can be observed from Table 3 that the dual-mode transit system meets or exceeds the achievement of the conventional bus rapid transit plan in almost all areas cited.

Possibly the greatest benefit offered to the community by the dual-mode transit system would be the increased availability of transit service, thereby providing increased access to jobs, health care, and educational and recreational opportunities, eventually leading to overall improvement in socioeconomic conditions. On a longer term basis, the guideway facility, having an excess capacity that can absorb future demand, will be a definite asset for the community in terms of efficient land resource utilization. The high-capacity guideway can reduce the need for additional freeway facilities as existing facilities become overburdened.

Possibly the greatest advantage of the conventional bus rapid transit system, in terms of regional goal attainment, is that it is based almost entirely on the use of existing traffic facilities and requires very little acquisition of new land.

In summary, the dual-mode transit system appears to better fulfill most regional goals, with the sole exception of right-of-way requirements. Dual-mode right-of-way acquisition will, on a long-term basis, however, reduce the need for arterial street, highway system, and freeway expansion, whereas any new right-of-way for the conventional bus system will only directly serve the transit user.

System Operating Costs, Capital Costs, and Fares

Annual Capital Costs—Comparative annualized capital costs and relative cost distributions, assuming 50-year, 25-year, and 15-year amortization schedules at 6 percent, for fixed facilities, stations, and vehicles respectively, are shown in Figure 7. It is seen from the figure that the cost distributions for both systems are nominally the same and that the dual-mode transit system in terms of absolute costs requires a substantially greater investment, primarily because of the high guideway investment.

In comparing these costs, it should be remembered that the service levels provided by the dual-mode transit and the conventional rapid transit systems are not equivalent. An examination of the relative labor productivities of the two systems emphasizes this particular point. Table 2 gave the relative number of vehicle-miles, vehicle-hours, and driver-hours utilized in each of the two systems during the peak hour. Note that,

Table 3. Regional goal attainment of dual-mode and rapid transit systems.

Regional Goals and Objectives	Rapid Transit Plan Evaluation	Dual-Mode Transit Evaluation
1. Improve selected socioeconomic conditions through improved accessibility[1].	All of the standards are met except that the entire service area does not have a maximum of 40 minutes travel time to all universities.	The average transit trip is reduced by 3.1 minutes (8 percent), correspondingly increasing the degree to which each of these standards is met. Longer average trip length also indicates a higher level of achievement.
	The majority of transit trips (~75 percent) originate via an auto ride from the trip origin and subsequently transfer at a park-ride station.	Dual-mode eliminates the need for a private auto trip, local bus travel (if available), or a walk to the transit system. This is particularly important to disadvantaged neighborhoods. Thus, the dual-mode availability should significantly improve neighborhood accessibility to increased jobs, education, health care, and other opportunities.
2. Enhance, through improved accessibility, existing and planned high-intensity land-use development.		
A. Regional centers to be connected to the CBD.	All major centers are served.	Same level of achievement as noted above. The route configuration is identical.
B. Service to existing land uses to be emphasized.	All major nonresidential developments are served. Transitway serves high proportion of special generators.	
3. Achieve a positive environmental impact in terms of system aesthetics and reduced air and noise pollution.		
A. Transit facilities should minimize harmful effects on the environment.	No perceivable detriments to the environment are apparent.	Same.
B. Minimize noise levels.	Interior and exterior noise levels are reduced. Transit vehicle noise is along existing freeways so new barriers are not created. External vehicle noise is 90 percent of conventional bus.	Noise reduction (both interior and exterior) will be considerably greater through use of smaller, less powerful transit vehicle.
C. Minimize air pollution.	RTX emissions are 33 percent of conventional bus and 15 percent of automobile. Per passenger carried, RTX is 200 times more efficient than automobile without pollution control device.	Air pollution reduction will be considerably greater through electric power on guideway, which will carry two-thirds of total vehicle-hours.
D. Minimize disruption on aesthetics of buildings, vistas, etc.	No major vistas are violated or views of buildings and landmarks obscured.	May not be fully achieved (detailed right-of-way location is not identified).
4. Minimize the disruption of desirable existing neighborhoods and communities.		
A. Transit facilities to preserve desirable existing facilities.	Routes are on or adjacent to existing barriers. Disruption of recommended transitway is minimal.	Detailed right-of-way locations studies were not undertaken. However, it is estimated that 50 percent of the network could lie astride existing freeways and another 15 percent along existing railroads and utility lines. Separate right-of-way is one-half to one-third of freeway requirements.
B. Preserve historic buildings.	No historic buildings are taken.	Impact is unknown, probably small.
C. Preserve park areas.	No major park is intruded upon.	Impact is unknown, probably small.
D. Minimize acreage acquired for transit.	No new land is needed for modified transit. Ride-park facilities are on vacant land or air rights except in one location. Transitway utilizes vacant areas or railroad right-of-way for the bulk of its length.	Detailed right-of-way location studies not undertaken. Possibly one-third of network right-of-way needs would require new land acquisition. Once committed, however, the availability of the guideway facility should serve to absorb excess capacity demands made on existing freeways, thereby deferring the need for continued rapid expansion of freeway facilities.
E. Enhance multiple use of land.	Transitway and railroad are proposed for same right-of-way. Joint projects analyzed for all station areas. State Fair Park and Model Cities area show greatest potentials. The modified rapid system is almost totally within the freeway right-of-way.	Increased ridership accelerates the desirability of key station areas for joint development.
F. Provide outlying parking area.	Park-ride lots are provided at all transit stations where any demand was established; a total of 33,000 spaces were provided.	Acreage requirements for these facilities will be greatly reduced.

[1]Transit should provide access to essential services according to the following: (a) 30 minutes to 40 percent of employment; (b) 35 minutes to three retail areas; (c) 40 minutes to major medical centers; (d) 40 minutes to regional recreation; (e) 40 minutes to vocational and higher educational centers.

Figure 5. Annual transport benefits for the dual-mode and rapid transit systems.

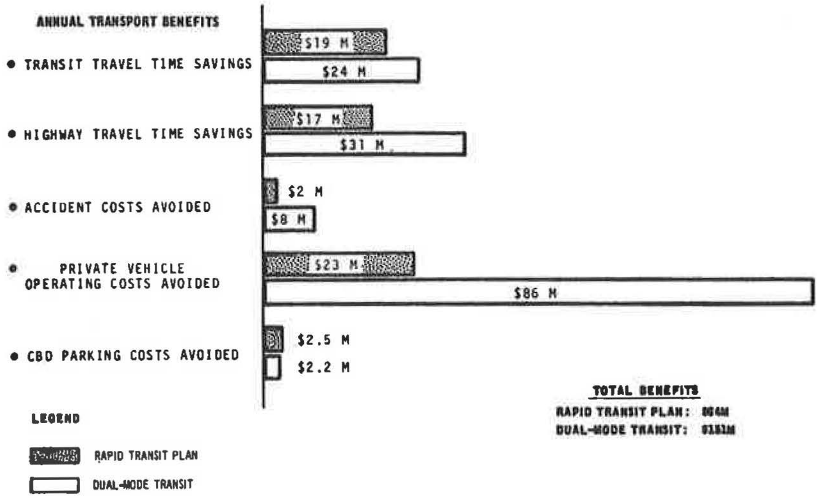


Figure 6. Annual transport costs for the dual-mode and rapid transit systems.

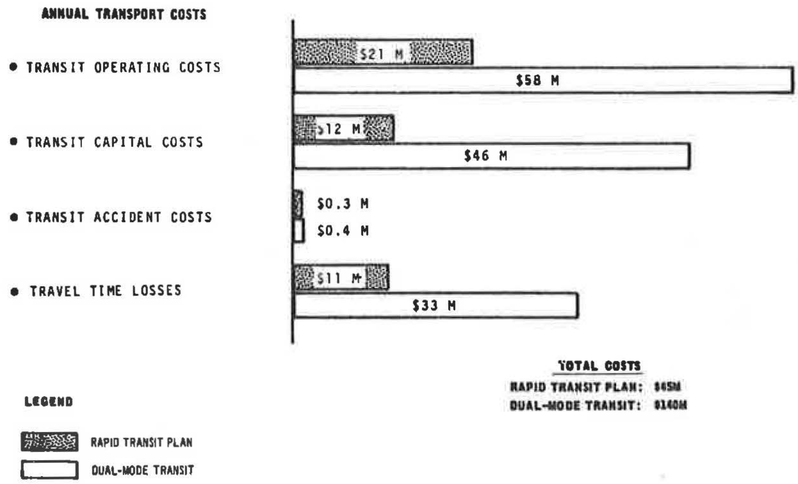
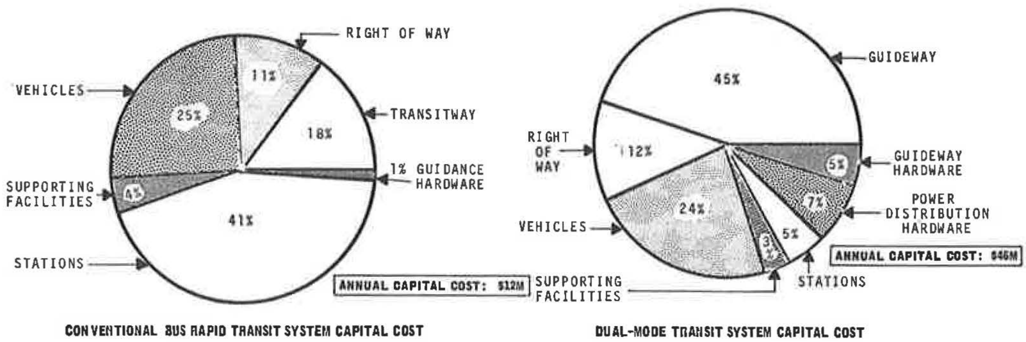


Figure 7. Annual capital cost and cost distributions for the dual-mode and rapid transit systems.



in a given hour, there are more than six times as many dual-mode vehicles traveling more than six times as many vehicle-miles and requiring only twice the number of drivers. In short, there are many more dual-mode vehicles going many more places, as previously discussed, with considerably fewer driver-hours per vehicle-mile required.

Annual Operating Costs—The annual operating costs and the corresponding cost distributions for the dual-mode and conventional bus rapid transit systems are shown in Figure 8. It is seen that the dual-mode system has more than twice the operating cost (for twice the ridership level) of the conventional bus rapid transit system. Note that the various cost components remain roughly in the same proportions and that dual-mode driver costs still represent about 31 percent of total operating costs. It will be shown subsequently that this added cost is the price for a high quality-of-service operating strategy. Other alternative operating strategies are available that could lower the operating cost of the dual-mode system to below that of conventional bus rapid transit, assuming that compromises in service levels can be tolerated accordingly.

Fares—If a flat fare structure is assumed, the fare required to cover all operating costs for one person-trip (an average distance of 14.2 miles on the dual-mode system) will be only 60¢, as shown in Figure 9. If both capital and operating costs are to be covered by fare-box revenues, a fare of $1.08 is required. This fare is not to be confused with an actual fare that is likely to be charged to the commuter. This fare includes total system costs, which are not normally entirely defrayed by fare-box revenue alone. Note also that this fare, on a per-passenger-mile basis, is very comparable to the cost of the conventional bus rapid transit system.

Figure 8. Annual operating costs and cost distributions for the dual-mode and rapid transit systems.

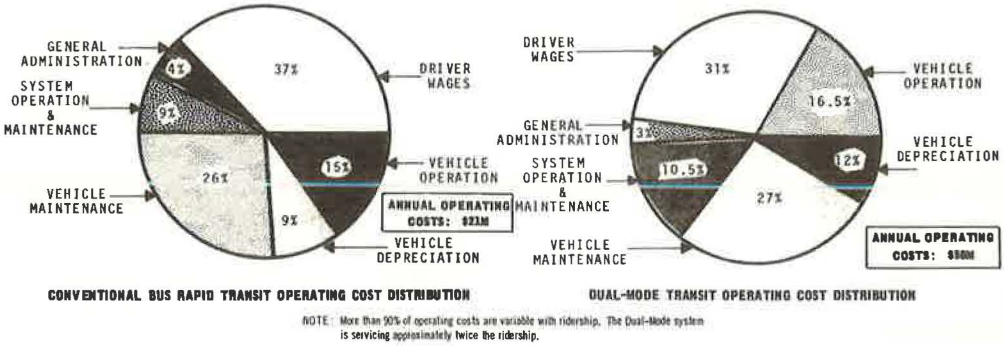
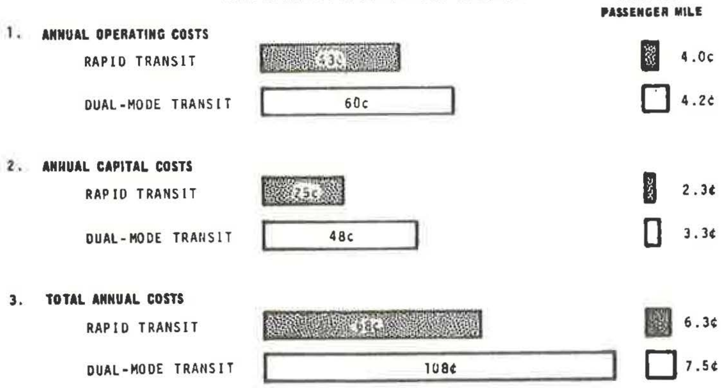


Figure 9. Fare requirements for the dual-mode and rapid transit systems.



SENSITIVITY ANALYSIS AND FUTURE GROWTH POTENTIAL

Sensitivity Analysis

In reviewing the previous case study results, it should be noted that the dual-mode transit system operating strategy and service characteristics were chosen in order to achieve a very high quality of service. It is important to recognize that there are many other, alternative dual-mode system configurations and operating strategies that might have been chosen to achieve other service levels. Although it was not possible to examine these alternatives in depth, some estimates have been made of system cost-performance sensitivities to changes in selected operating and configuration factors. Sensitivity to forecast ridership levels was also examined. Highlights of this analysis include the following preliminary findings:

1. A halving of ridership would increase operating costs per passenger by 6 percent and capital costs per passenger by 61 percent (total required fare of $1.40).
2. A doubling of ridership would reduce operating costs per passenger by 2 percent and capital costs per passenger by 25 percent (total required fare of 94¢).
3. Required fares and transport benefits were most sensitive to changes in mainline speed. An increase from the simulated 55 mph to 70 mph could reduce the total fare by 10 percent while increasing benefits by 21 percent.
4. An increase in guideway mileage (or number of guideways) from 110 miles to 165 miles would increase annual capital costs by 21 percent, total required fare by 4 percent, and annual transport benefits by 15 percent. This increase would also improve the benefit-cost ratio.
5. An increase in vehicle size to 53 passengers per bus could reduce operating costs per passenger by 33 percent (to less than those under the rapid transit plan) while increasing capital costs per passenger by 6 percent (total required fare of 91¢). There would be a somewhat detrimental effect upon the benefit-cost ratio, however.
6. Other service characteristics, such as headways, station spacing, network scope or coverage, and proportion of captive vehicles (no manual-mode operation), were also examined and generally showed less significant impact on system costs and benefits.

A more comprehensive discussion of these cost-performance characteristics is given in the Volume 3 report (17). These results illustrate two important points: first, the dual-mode system chosen for the case study comparative analysis could readily be made even more cost-effective with further study, and, second, the dual-mode transit system offers a wide latitude of operational flexibility.

Assessment of Initial Economic Impact of Private Vehicle

The potential added revenue to the dual-mode transit system due to the incorporation of the private dual-mode vehicle was also examined in the case study. In addition to dual-mode transit, private dual-mode vehicle ridership on the guideway network was also forecast with the aid of local transportation forecasting models. It was assumed that the early versions of dual-mode private vehicles would likely be premium priced, and, as a result, the likelihood of having access to a dual-mode vehicle was assumed to be a linear function of the forecast number of autos per household. Using this assumption, together with travel time diversion curves, the patronage of the guideway system was estimated. During the peak hour, in 1990, the critical link loading (transit and private vehicles) on the entire 110-mile guideway network was found to be only about 2,000 vehicles per hour per lane—a fraction of the maximum theoretically attainable capacity of the guideway.

In spite of the relatively light guideway loading, significant economic and other benefits result in the mixed-vehicle system. After taking into account added capital costs for new facilities (such as interchanges and separate downtown distribution segments) required to accommodate the private vehicle, as well as increased guideway operating costs, revised fare requirements were determined. Under the assumption that fares would be equalized between private vehicle and transit users (in which case the transit operation is being subsidized by private vehicle users), the former operating cost (fare) per person trip of 60¢ is reduced to 30¢. After taking capital costs into account, total annual costs could be completely recovered with a fare of 61¢ per person or vehicle trip.

SUMMARY OF SOCIOECONOMIC EVALUATION CONCLUSIONS

The case study analysis showed a hypothetical dual-mode transit system to be superior to the conventional bus rapid transit system in terms of performance:

1. Ridership doubled;
2. Trip time decreased an average of 8 percent, ranging from 3 to 17 percent;
3. Transfers were significantly reduced (from 94 percent to 21 percent for trip origins);
4. Collection-line-haul-distribution service, virtually door-to-door, was provided;
5. System availability increased more than sixfold (more neighborhood routes); and
6. Comfort and convenience improved.

In terms of user costs and benefits, the dual-mode system had higher costs with commensurately higher total benefits. Both systems showed annual benefits exceeding costs.

From the viewpoint of productivity, the dual-mode transit system showed more than three times the productivity of the conventional bus rapid transit system. More than six times the number of vehicle-miles of service were provided by the dual-mode system, requiring only twice the number of drivers. This is attributed to the fact that 70 percent of the time the vehicles are operated in a driverless mode, so that the driver pool focuses solely on the provision of manual collection-distribution service.

Fares required to cover all operating costs (including vehicle depreciation) were 60¢ for the dual-mode system as compared with 43¢ for the conventional bus rapid transit system. Although the dual-mode system required a higher fare, the fare increase appears very likely to be acceptable to the consumer because it is a small increase in proportion to the significantly higher quality of service offered.

The sensitivity analysis illustrated a high degree of operational flexibility in the dual-mode transit concept, providing operational strategy options not available in conventional systems (such as dynamic neighborhood routing, captive versus off-guideway operation trade-offs, and trade-offs among various dimensions of high-quality door-to-door service).

Possibly most important, the dual-mode system can serve not only transit but the total urban transportation need. Consideration of a relatively small loading of private vehicles (i.e., in addition to transit vehicles) on the case study system showed the potential for significantly increased revenues—a possible subsidy for transit—as well as increased benefits for the community.

It is concluded that the hypothetical dual-mode system would be an attractive alternative to (or extension of) the conventional bus rapid transit system proposed to serve 1990 Milwaukee transit needs. The system also has desirable characteristics that would appear to be of value for most other medium-to-large metropolitan areas nationwide.

It is concluded from the high level of benefit-cost performance and the achievement of regional goals characteristic of the dual-mode transit system, as evidenced in the case study results, that dual-mode offers attractive advantages as a transportation system for the urban community.

ACKNOWLEDGMENTS

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