CONCLUSIONS AND IMPLICATIONS FOR FUTURE BUSWAYS

This demonstration project has shown that busways can be cost effective, noncontroversial, and attract substantial numbers of solo automobile drivers to buses and carpools.

Busways would be most cost effective in bus-only operations if sufficient demand existed to fully utilize available capacity. When sufficient bus ridership demand does not exist, or when its development is uncertain, carpools may be added to increase the cost-effectiveness of busways with only minor impacts on bus operations. When bus demand is uncertain, the busway design should permit carpools to be added, limited, or removed as circumstances change during the life of the busway.

Demand data from this project have shown that a properly designed busway can attract a mode share similar to that of a comparable rail facility, at substantially less cost. The collection and distribution function served by the same busway buses reduces or eliminates the transferring required for a typical rail trip. The ability to increase cost-effectiveness by the addition or deletion of carpools makes a busway more adaptable than rail to changing or uncertain future circumstances. Of course, if total demand grows beyond the busway capacity, conversion to a higher-capacity rail line is possible.

For maximum cost-effectiveness, each major aspect of the busway design should be examined to determine that its cost is justifiable in terms of the additional users that it will attract. To minimize adverse impact, busways should be physically separated from adjacent freeway traffic and should not begin or end at places where the freeway will be congested—where these features can be achieved in a cost-effective manner.

Finally, busways are most appropriate for congested freeway corridors. If congestion does not exist or is eliminated, much of the attractiveness, and effectiveness, of the busway would be lost.

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Abridgment

Analysis of Bus Systems to Support Rail Rapid Transit

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This abridgment describes an evaluation of alternative bus systems that will serve as line-haul and feeder service for the Metropolitan Dade County Stage 1 Rapid Transit System (Miami area). The weighted derivative (sensitivity) of transit ridership is defined and computed for all study-area zones, zone pairs, districts, and district pairs. Then a comprehensive transit system is determined for the study area to aid in the planning process. These two concepts are applied to a large urban area by using the urban transportation planning system (UTPS) and UTPS-compatible programs.

Transit planning by use of UTPS for large urban areas generally precludes the use of optimization techniques in the design of bus route systems. The large networks, long computer execution times, and impenetrability of the UTPS programs all combine to make optimum use of UTPS at the detailed planning level difficult. Previous studies of optimization concepts generally dealt with smaller networks that have fewer than 100 nodes (1-3). The concept of the weighted derivative is motivated by the desire to use a gradient-type interactive approach to make changes in the bus route system. Knowledge of the potential change in ridership due to changes in travel disutility can guide the planner in making changes to increase ridership at the least cost. Although the approach used did not iterate in the usual sense, the information provided gives new insight for the two route systems studied and helps explain why one is superior to the other.

The concept of a comprehensive transit system is not new, but its application in a UTPS setting is (4,5). Sometimes called an ubiquitous system, a comprehensive transit system is an abstract concept defined by the following service characteristics:

1. It covers the entire service area,

2. Each potential traveler has access to the system near trip origin and destination,
3. Headways are short,
4. Paths are not circuitous, and
5. There are few or no transfers.

In short, it is assumed that the numbers of vehicles and routes are unlimited. Transit fare and costs of competing automobile trips are assumed to be the same as for a design system. Such a system will attract the maximum potential ridership for any system by using the same vehicle types and speeds. The planner obtains an upper bound on ridership for evaluating various design systems. Detailed comparisons between a comprehensive and a design system on connectivity, ridership, travel times, and disutility can aid in modifying the latter. A comprehensive system can also aid in designing a new transit system (6). For Dade County the major use was to evaluate design systems.

APPROACH

The approach of the analysis is described by eight steps:

1. Develop initial alternative bus systems. For Dade County these are two—NET 6, a modified version of the existing system plus committed extensions and additions, and GRID 1, prepared by Dade County Office of Transit Administration. Both of these systems had already undergone considerable refinement before being subject to the present analysis.
2. Develop comprehensive transit system as a reference system. A 1985 highway network was used, and automobile speeds were factored down to appropriate bus speeds. Additional links were added to the resulting network to represent the 34-km (21-mile) long stage 1 rail line and a number of express busways.
3. Use UTPS program package to evaluate each system, generate paths, modal splits, and line assignments. Compatibility with UTPS was a requirement because virtually all previous planning had been performed with Federal Highway Administration (FHWA) and UTPS programs.
4. Generate reports of service indices and potential ridership changes for each alternative. The same program provided data on zone coverage, ridership, trip times, transfers, and the derivative of the modal split function. Most of the data were aggregated to district trip-end summaries and district-district tables.
5. Generate reports of resources needed: vehicles and vehicle distances and hours traveled on routes.
6. Examine reports to determine if further improvements or resource and patronage trade-offs can be made.
7. Use detailed output reports to make changes, then go back to step 3.
8. Stop. This decision was based on the time, manpower, and computer resources needed to perform another iteration versus the likelihood of achieving a significantly better bus system.

DESCRIPTION OF PROGRAMS

The program package consists of a sequence of UTPS programs (7); they are UNET, UPATH, UMODEL, ULOAD, and UFMTR. (These computer programs were designed for U.S. customary units only; therefore, values given are not in SI units.)

Comprehensive Transit System Development

Considerable effort was spent on the development of the comprehensive transit system. The first step assumes existence of a capacity-restrained highway assignment, which yields congested automobile speeds. FHWA program UNBLDHR is used to produce link cards from the historical record office (HRO) file (8). Highway link times are used to derive bus speeds by using the formula

$$T_b = T_a + L^2/(2ST_a) + 0.2L/S \tag{1}$$

where

T_b = bus time on link (min),
T_a = automobile time on link (min),
L = length of link (miles), and
S = bus stop spacing on link (miles).

The second term expresses delay due to acceleration and deceleration of the bus and the third term reflects passenger boarding and alighting times. This formula is similar to one in McFadden and others (9). Bus spacing is a function of automobile speed:

$$S = (0.007)\,(\text{automobile speed}) + 0.12 \tag{2}$$

Spacing is confined to the interval (0.17 mile, 0.33 mile), and the final bus speeds are confined to the interval (8 mph, 30 mph). Access to the comprehensive transit system is by walk connectors. These are the same as the centroid connectors to the 1985 highway net, except that walking speeds of 3.0 mph are assumed.

UMODEL Program

The key program in the analysis is a UMODEL routine with user-coded subroutines. The program reads zonal data, fare and toll matrices, parameters, and trip table data and then performs modal split for each interchange or zone pair, computes performance indices, and writes outputs. Person trip data used were for 1985, with four purposes defined: home-based work, home-based other, nonhome based, and school. Time and distance skims are for peak and off-peak. Also, trips are differentiated by origin zone location: beach area and nonbeach.

Modal Split

A logit model is used to predict transit choice (9):

$$\text{fraction transit} = 1/(1 + e^x) \tag{3}$$

in which $x = sDD - aDA - b$

where

DD = disutility on design transit system (for comprehensive service, DC is substituted for DD),
DA = disutility for automobile trip, and
s, a, and b = constant coefficients for trip categories.

Disutility for a transit system (DD or DC) is obtained by

$$DD = \text{run time} + \text{fare disutility} + (\text{walk and wait time} \times 2.5) \tag{4}$$

The automobile disutility (DA) is given by

DA = run time + terminal time + parking cost disutility
+ automobile operating cost disutility (5)

Weighted Derivative

It is useful to know how sensitive system output is to changes in inputs. Previous work on mode choice (10) indicated that certain purpose-location-income group (PLI) combinations were far more sensitive to changes in transit service than others. Also, for a given PLI combination, the sensitivity to changes depends on the difference between transit and highway disutilities. This concept is expressed mathematically by the derivative of the modal split function, evaluated at the weighted disutility difference (x) for a design system under consideration:

$$DER = -e^x/(1 + e^x)^2 \quad (6)$$

The DER is multiplied by total person trips to show the change in transit ridership due to changes in x. This yields the weighted derivative (WTDER):

WTDER = DER x total person trips for zone pair (7)

The WTDERs are then aggregated to give district trip-end summaries and district-district tables.

These WTDERs must be interpreted with caution. At any aggregation level there is an assumption that a change in x for all person trips involved causes transit ridership to increase. Improvements in service to one or more zonal interchanges that cause the total district interchange to improve one disutility unit may not improve the transit ridership by the value WTDER. WTDER is computed with respect to x. For different PLI combinations, x exhibits different sensitivities for changes in DD or DA. For widely differing values of the coefficients, the WTDERs should not be aggregated. In summary, the WTDER values are another output of the program. Properly interpreted, they can aid the planner in making changes in the system.

Area-Adjusted Weighted Derivative

A problem in interpreting WTDER is that it is unrelated to the cost of changing the transit service. To adjust for the cost of improving transit service, by lower headways, closer line spacing, or faster bus speeds, one should modify WTDER based on these factors. Little work exists on such relationships—what has been reported suggests that some of the cost factors are related to the area of the district being served (11). Thus, it was decided to divide the WTDER for a district by the area of the district, giving the area-adjusted weighted derivative.

Program Time and Size

The program sequence was run on an IBM 360/65. Constraints that affect time and size include: number of tables input (24) and output (26), zones in the network (723), and nodes in the transit (2200) and highway (9000) network. A complete run takes about 250 central processing unit (CPU) min. Nearly half of that time is used by the UMODEL program, which also requires the largest amount of core, 616 000 bytes.

APPLICATION AND ANALYSIS

Summary details are given below for the bus lines in NET 6 and GRID 2, a revised version of GRID 1:

Variable	NET 6	GRID 2
Bus lines	137	103
Route miles	2 466	1 896
Vehicles	921	931
Vehicle miles	200 000	177 000
Vehicle hours	15 600	13 800

The most evident difference is in the higher route miles, vehicle miles, and vehicle hours for NET 6. One of the purposes of NET 6 is to provide service to an expanded area. This is also clear from an examination of the connected zones and interchanges.

Service to	NET 6 (%)	GRID 2 (%)
Peak zones	92	90
Interchanges		
Peak	82	80
Off-peak	77	80
Total person trips		
Peak	95	93
Off-peak	93	91
Average	94	92

NET 6 provides service to 2 percent more zones and interchanges during the peak than does GRID 2. During the off-peak, however, NET 6 coverage is reduced to 3 percent fewer interchanges than GRID 2.

Superior Performance of GRID 2

The GRID 2 system performs slightly better in terms of patronage and modal split.

Modal Split	NET 6 (%)	GRID 2 (%)	Comparable Service (%)
Peak	12	13	19
Off-peak	5	5	7
Total	6.5	7	10

GRID 2 attracts more peak rail patrons, but fewer during off-peak. Average disutility of travel time is 0.7 min less on GRID 2. As expected, transfers are higher for GRID 2 than for NET 6—1.4 and 0.7 versus 1.3 and 0.6 for peak and off-peak, respectively.

The major difference between the two systems is in productivity. Peak productivities are nearly the same, but the off-peak figures favor GRID 2—1.3 passengers/vehicle mile versus 1.1 passengers/vehicle mile and 18 passengers/vehicle-h versus 15 passengers/vehicle-h. NET 6 uses 22 percent more vehicles and 19 percent more vehicle miles during the off-peak and yet attracts only 1 percent more off-peak patrons. These differences are substantial: 131 more off-peak buses and 23 000 more off-peak vehicle miles (12).

Balance and Sensitivity

More detailed analysis shows that GRID 2 performs better for nonbeach work trips and low-income trips; however, NET 6 provides better service for beach zones. GRID 2 gives better service in the core area, and NET 6 serves the peripheral and beach areas better. The area-adjusted WTDERs indicate where cost-effective changes in transit service can be made. These WTDER values can be aggregated at higher levels to compare large areas against one another.

Area-Adjusted WTDER for	NET 6 Peak	NET 6 Off-peak	GRID 2 Peak	GRID 2 Off-peak
Central area	467	499	474	494
Periphery	114	168	150	236
Beach area	906	3290	888	3017

This comparison provides some numerical values about how much more difficult it is to gain riders in the peripheral areas. If transit disutility is reduced by 4 min throughout an area (4 times a typical s value of 0.25 = 1.0), the resulting increase in ridership will be about 467-499/mile^2 in the peak, and 114-236/mile^2 in the off-peak. The beach districts have the greatest area-adjusted WTDERs. NET 6 and GRID 2 are fairly comparable in the core and beach areas but differ markedly in the peripheral area.

CONCLUSIONS

Two concepts were applied in the transit planning process for a large urban area by using UTPS-compatible programs: the weighted derivative of transit ridership and a comprehensive transit system. Because design of bus route systems for Dade County had progressed considerably before application of these concepts, they did not lead to major changes in alternative transit systems. However, they did provide clear and meaningful new insight in explaining the superiority of one route system. In particular, it was judged that a grid bus system was able to achieve higher productivity because it concentrated service in the core districts, which have much greater weighted derivative values. Since the comprehensive system attracted about the same number of riders for both connected service areas, the difference between the two design systems is largely in emphasis on different areas. It is hoped that these concepts will be used to guide subsequent refinements of the grid system.

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Discussion

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The authors should be commended for their attempt to rationalize the design of a complex transit network. Several aspects of the paper, however, merit further discussion. Essentially, two transit networks proposed for Dade County, Florida, are compared with an ubiquitous network. The concept of an "area-adjusted weighted derivative of transit ridership" is also introduced.

A section of the paper is devoted to describing various idealized bus transit networks (such as grid and radial) that have been discussed at length elsewhere (5). Somewhat surprisingly and contrary to the title of the paper, feeder route systems and their orientation to fixed guideways (13, 14) are not discussed.

An ubiquitous transit network is rather attractive for the purpose of comparing such variables as total ridership. However, one should be careful because the system operating costs cannot be compared in a similar manner. Further, care should be taken in the definition of an ubiquitous system in a practical situation for purposes of comparison. For example, the sensitivity of the results to the arbitrary assumption of a 10-min headway between buses should be checked.

The highway link time formula given by Equation 1 is based on several assumptions that should be noted. The term $L^2/2ST_a$ is dependent on both the acceleration and deceleration of a bus being equal to 4 miles/min^2. The last term 12/S seems to be based on the heroic assumptions that the link lengths and the number of passengers that board and alight in each link are equal. The basis for the formulation of the bus stop spacing as a linear function of speed (given by Equation 2) is unclear. It has been shown elsewhere (15) that the spacing that minimizes the sum of the passenger time costs and bus operating costs (total cost) is proportional to the square root of the bus speed.

It is likely that the disutility of a transfer is composed of two parts: one related to the waiting time and one related to the intrinsic inconvenience. In other words, an intrinsic transfer disutility would exist even if the transfer time was zero. This fact should be reflected in the transit disutility function given by Equation 5, since up to three transfers are allowed in the transit networks being compared.

It is recognized in the paper that the "weighted derivative of transit ridership (WTDER)" is unrelated to the cost of altering the service and, hence, of little value. The proposed remedy—the division of the WTDER for a district by the district area to obtain an estimate of the sensitivity of the change with respect to cost—leaves much to be desired. The WTDER for a district (as I understand the paper) is the change in trip ends between all the zones in a district and all the zones in the study area inclusive of that district, when the (DD - DA) values are decreased by one unit. Thus, the division of WTDER by the district area to obtain the sensitivity with respect to operating cost is not helpful since the district area cannot be a surrogate for the cost of operating buses, let alone trains, between zones in the district and zones outside the district.

The "superiority of one route system" over another cannot be established without more explicit recognition of the operating cost of the systems. A good transit system is one perhaps where a balance is obtained between the level of service and the operating cost. Recent work in the area of optimal bus transit networks (16) has indicated that a grid is not likely to be better than an asymmetric network if the total cost is to be minimized.

Finally, the inclusion of sketches of the two networks (NET 6 and GRID 2) would have been helpful.

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Author's Closure

Gunter P. Sharp

Wirasinghe's discussion contains a number of valid comments. Some points mentioned should be clarified.

The formula for bus link times (given by Equation 1) originally contained an error and should read

$$T_b = T_a + L^2/(2ST_a) + 0.2\ L/S \quad (1)$$

The second term ($L^2/2ST_a$) does not imply bus acceleration and deceleration of 4 miles/min^2 but instead relates to the additional acceleration and deceleration time needed for bus rather than automobile. The third term (0.2 L/S), which previously contained the error, is based on 0.05 min/passenger and four passengers/stop.

Bus stop spacing was expressed as a linear function of speed because this was thought to provide a good, simple approximation of current and future practice by Dade County. Stop spacing is influenced heavily by the type of street and spacing of blocks.

The disutility of a tranfer was expressed in a manner consistent with previous mode split analysis for the system, so that comparisons could be made more easily between the one-step logit model and the hierarchical model used previously (10).

The division of the weighted derivative of transit ridership (WTDER) by the area of the district is intended to yield a measure of potential ridership increase per square mile. Such a measure is clearly helpful to the planner even if the relation between district area and bus operating cost is not well specified.

It is stated in the paper that the superiority of the GRID 2 system is based on productivity and sensitivity. Since both systems attract about the same total numbers of patrons, the higher productivity of GRID 2 translates into lower operating costs. Thus, operating costs are explicitly recognized.

The term grid is something of a misnomer for the GRID 2 system. A more detailed analysis of route types in each system gives this comparison.

Peak Vehicles by Route Type	NET 6 (%)	GRID 2 (%)
Routes oriented mainly east-west or north-south, local	42	60
Radially oriented routes, local	12	11
Routes of mixed type, local	28	11
Express routes of all types	18	18

The express routes are mainly radially oriented and of mixed type and are the same in both systems. The difference between the two systems is a matter of degree; either one might be classified as being an asymmetric network.

The route systems require eight or more figures for clear graphical representation; these were excluded because of page limits. The Grid Bus Analysis (12) contains a complete set.

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