Using Regional Forecasting Models of the Urban Transportation Planning System for Detailed Bus Route Analysis

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ABSTRACT

Planning bus system operations has traditionally relied heavily on the acquired knowledge of bus system planners and has been one of the last areas of transportation planning to be computerized. There are a number of programs available to design the allocation of drivers and vehicles to a bus system, but the planning process still lacks a detailed capability to determine the desired headways and short lines based on the levels of demand for service. Conventional wisdom has held that the regional forecasting models, based on zonal-level analyses of trip generation, trip distribution, mode split, and assignment, are too aggregate and too coarse to permit them to be used to assist in such planning efforts. There is no question that these models are coarse and aggregate. However, this paper demonstrates that they are still sufficiently realistic and accurate to be used for bus route planning at a line-by-line level and that for large bus systems they may be much better suited to the planning issues involved than any other available methodology. Some specific requirements that the models must meet to be used in this manner are described. A procedure is detailed for producing bus system statistics from the standard planning models of the Urban Transportation Planning System (UTPS) and it is shown how this procedure can be used in conjunction with the UTPS procedures to undertake detailed long-range planning of a bus system. The capability of the procedure to produce data that accurately reflect the base year is shown to be considerably greater than that normally associated with aggregate travel-forecasting models. The capability of using the procedure to refine a long-range bus system is demonstrated in a case study from the Los Angeles area, and this shows that the procedure has the capability to provide clear indications of a variety of improvements to the efficiency of the planned bus network.

Planning bus system operations has traditionally relied heavily on the acquired knowledge of bus system planners and has been one of the last areas of transportation planning to be computerized. In the present state of the art, there are a number of programs available to design the allocation of drivers and vehicles to a bus system [e.g., RUCUS and HASTUS (1-4)], each of which works on a line-by-line basis and is capable of determining an efficient, although probably not optimal, allocation of both drivers and vehicles. These tools allow a system to put into practice the service configuration that has been determined from other considerations, for example, changes in service levels to meet demand and changes that may be indicated to reduce operating costs.

This planning process still lacks a detailed capability to determine the desired headways and short lines based on the levels of demand for service. Perhaps more important, bus system planning has been undertaken only on a short-range basis with any degree of detail. Long-range planning of bus system configurations has not been attempted to a large extent, even though part of the planning of future long-range capital investment in transit should consider the implications for fleet size and system operation. Conventional wisdom has held that the long-range regional forecasting models, based on zonal-level analyses of trip generation, trip distribution, mode split, and assignment, are too aggregate and too coarse to permit them to be used to assist in such planning efforts. There is no question that these models are coarse and aggregate. However, the authors believe that it can be demonstrated that they are still sufficiently realistic and accurate to be used for bus route planning at a line-by-line level and that for long-range future planning they may be much better suited to the planning issues involved than any other available methodology. There are some specific requirements that the models must meet to be used in this manner, and there will remain a need for a significant level of professional judgment to be applied to the final results. Nevertheless the basic conclusion is that the models are capable of assisting the planning process at this level of detail and particularly for long-range planning applications.

In the remainder of this paper the goals of this procedure, the steps required to develop models that are of sufficient accuracy to be used in this manner, and a computer program (URAP) that works with the Urban Transportation Planning System (UTPS) (5) models to produce the information needed for route-level planning are described. A case study of the application of the procedures is given to demonstrate how the procedure can be used to refine service levels that would feed that next step of the process--the development of run cuts and schedules.

GOALS OF THE PROCEDURE

The primary goals of this procedure are to be able to develop changes in bus route service levels that are consistent with demand for bus service and known elasticities of demand and to provide a basis for estimating changes in service levels required for long-range planning purposes well beyond the time frame usually associated with detailed bus route planning. It is also intended to systematize the trial-and-error procedures that are more likely to be used in long-range planning for bus service changes and to provide a bus system design that represents one possible system to meet demand at a reasonable level of efficiency and with prespecified policy requirements for service.

DEVELOPMENT OF THE TRANSIT NETWORK

Fundamentally, the route-analysis procedure consists of refining the transit network description in terms of both the transit lines themselves (deletion of transit lines and definition of short-line operations) and changes in headways. Therefore, it is important that the transit network be built to provide as realistic a simulation of the actual transit system as possible. If the transit network is not a careful, realistic simulation, planning of bus route revisions will necessarily be too inaccurate to be useful, and one would also need to question the degree of inherent accuracy in any individual line loadings. However, in case it should be construed that the levels of accuracy indicated here are required only to enable the route-analysis procedure described in this paper, it should be stressed that most transit networks are not built with adequate attention to detailed realism and are likely to provide misleading results for any long-range planning application. The level of accuracy described here is necessary to the route-analysis application, but it should be achieved in any case for realistic transit planning of any description.

Ideally, two network definitions are needed--one for the morning or evening peak and one for the midday period. For each of these, the network description will show the appropriate average headways for the period, the average speed or travel time on each link of the network in each period, and line descriptions over the network for each bus line and significant subline operation. A number of aspects of the development of the transit network are worth reviewing, because they have a marked effect on the accuracy and realism of the network and because they include a number of judgmental aspects of transferring actual bus lines into state-of-the-art transit network methodology.

A careful study of existing bus system operations is required initially, ideally focused on defining the headways. It is recommended that average headways be developed by counting the actual numbers of trips made on a bus route during each of the peak periods and in the base (midday) period. Average headways are defined by dividing the length of the period (peak or base) by the number of trips in that period. Counts of trips should be made from published schedules or the schedules used to generate work pieces for driver assignments. In either case, a control point should be defined for each bus route and the count of trips made at that point. In the process, and by looking at the beginning and ending points of each bus trip, the analyst can gain a rapid definition of the alternative short-line operations that are scheduled. These can then be developed into a definition of the sublines. The authors have found that it is preferable to define the count in the direction for each peak for which the trip count is maximized and to define the subline operations that occur in that direction only.

It is often suggested that the limitations in state-of-the-art networks make it best to define each bus route as two one-way routes. However, many problems are generated by such a definition, including a lack of ability to build in layover required to maintain headways on round trips and overestimation of the total number of vehicles required to provide the service. Because of this, the authors have found it preferable to define routes as two-way unless this makes it absolutely impossible to produce a reasonable simulation of a route. Even when a route traverses some segments of one-way streets, generally in the central business district (CBD), it is preferable to define the route as a two-way route and define a special two-way transit link on the one-way streets. Provided that care is taken in connecting walk links to nodes on such a two-way street segment, the resulting bus line will usually provide the most realistic simulation. Of course, genuine one-way routes, such as express bus services that operate only in the peak direction, should be defined as one-way routes. These should generally be the only such routes in the network, however.

Care is needed in defining the ends of bus lines that may make a loop, because state-of-the-art transit networks will generally prohibit a line from crossing itself. Coding to the midpoint of the loop, along one side of the loop, or around the loop to end at the division point are each possible strategies that should depend on the size of the loop and the extent to which appropriate connections from zone centroids can be provided along the nodes on the loop.

Subline operations often present serious coding problems, particularly when there are a large number of such operations on some lines. As a general rule, and bearing in mind that the goal of the network building is to provide a basis for demand forecasting, the sublines should be defined from the viewpoint of the bus user rather than from the viewpoint of the operator. Thus, suppose that A, B, C, and D are four points along a bus line with A being the beginning of the line and D the end of the line. The bus operator may run the following operations: a bus starting at A, driving to C, returning to B, proceeding to D, and then returning to A. The mirror image of this operation may also be scheduled, beginning initially at D with short runs to B, C, and finally A. This scheme may potentially define as many as eight distinct bus trips (A to C, A to D, B to C, and B to D and all the return trips). At a minimum, given the limitations of state-of-the-art transit networks, four two-way lines would need to be defined for this. However, most bus riders will perceive that the route offers three different headways: one between A and B, one between B and C, and one between C and D. Because relatively few riders will ride from one end to the other of the line, most bus riders will be unaffected by the fact that some buses do not offer service on the entire length of the line. Therefore, the line may, if headways are identical along AB and CD, be defined as two lines: one from A to D and one from B to C. If all operations are of the form described earlier, the line from A to D will have the base (lowest) headway, and the line from B to C will have half the base headway, because all buses traverse this portion of the line. Similar reductions in complexity of sublining need to be made for demand modeling to present an effective simulation of the bus system.

The speeds and distances on the network must also be scrutinized carefully. For a number of reasons, it is rarely possible for an aggregate coded network to produce line descriptions that exactly match the times and distances known to occur in reality. A more serious problem often arises because there is a lack of good information on the true times and distances on specific lines. In transit properties that have made a substantial number of recent route modifications, there may be fairly reliable information on the actual running times from beginning to end of a line, but no reliable information on the length of the line. Nevertheless, replication of true distances and times in the network description is most important to use of aggregate network tools to assist in defining service needs. The authors suggest that the line-by-line distances and times be checked carefully and that any falling outside a 10 percent error margin be reexamined carefully. This reexamination should consist of checking the network output reports to see if there is any link in evidence on which there is either a disproportionately long or short travel time compared with the length of the link. Second, careful examination is required of the line description to make sure that there are no "tunnels" or airline links that violate the geometry of the underlying street system.

Once a sufficiently accurate network description has been achieved, it is important to examine the results of a base loading of the network. For this, the entire travel-forecasting procedure must be run with base-year data. In examining the results, there can be no substitute for the person in most transit properties who has an encyclopedic knowledge of the system and its current loadings. Maximum loadings on each line should approximate fairly well the known maximum load points, both in location and volume. Further, the pattern of loading along the line should be reasonably close to reality. A long initial or final segment of line that runs empty in the assignment when buses are actually running with 20 to 40 passengers per bus would be an obvious indication of problems in the line description or the connections from the zone centroids to the transit network. There is considerable potential for error in transit assignments resulting from a poor choice of walk and automobile connectors to the transit network, so these assignments must be considered prime candidates for modification if loads are not found to match reality. In addition, it is most important that lines that share a common segment of street be described identically in terms of the network nodes traversed. In standard assignment procedures that share patronage on a common street segment among all the lines on that segment, a common street segment can be recognized only by absolute identity in segment descriptions. If the option to have loads split between common line segments in proportion to service frequency is used and common segments are not found to have proportional loadings, the fault is almost certainly in the lack of identity in the coding. The same applies for any other proportioning of the loads.

It cannot be overemphasized that a significant amount of time is needed to ensure that all such errors and problems are resolved and removed from the network. Any one of these errors will compromise the use of the network to assist in line planning. However, the accuracy achieved in this process is also necessary for many other aspects of long-range planning.

THE UTPS-COMPATIBLE ROUTE-ANALYSIS PROGRAM

In UTPS, there are two alternative transit network procedures. Although new applications are encouraged to use the newer INET procedure, which is built from the highway network and reflects existing highway loadings in determining bus speeds on shared right-of-way, many existing planning agencies use the older UNET procedure. UNET is based on an independent transit network, and congestion on the streets can be reflected only by a manual adjustment to the transit running speeds or times. The route-analysis program described in this section was developed principally to work with UNET networks. It can be used with INET networks, but some of its features are unnecessary in that context, because INET contains some capabilities that the route-analysis program was designed to add to UNET.

The UTPS-compatible route-analysis program (URAP) provides four primary features:

- Addition of several elements of line descriptions that add to the realism of the descriptions,
- Determination and reporting from the assignment of a number of statistics that are not available from standard reports,
- Computation of several alternative estimates of line-by-line service levels, and
- A capability to impose some service modifications and determine their effect on the system requirements.

It is beyond the scope of this paper to provide a detailed description of each of these features, details of which may be found elsewhere (6). A list of the tables provided by URAP is provided in Table 1. A brief description of the features is provided in this section. Computationally, URAP is extremely simple and involves primarily only the organization of data already available from the ULOAD assignment of trips to the transit network. In addition, there are no assumptions involved in the URAP program that are a function of size of the region, percentage of trips on transit, or size of the transit property or properties operating in the region.

TABLE 1 URAP Output Reports

Report No.	Contents	Optional?
1	Input global parameters	No
2	Input annual parameters	No
3	Input policy headway values	No
4	Line record information	Yes
5	Maximum load point summary	Yes
6	Operating statistics	Yes
7	Compressed operating statistics	Yes
8	Summary of total operating statistics	Yes
9	Annual statistics	No
10	Undefined headway values	No
11	Excess passenger demand summary	Yes
12	Operating cost model statistics	Yes

Primarily, URAP operates by taking certain user-provided inputs and using these to modify ULOAD data or compute additional statistics from the ULOAD and user-provided information. ULOAD assigns transit trips to the transit network and generates loadings by line and by link for the transit network. If steps preceding the use of ULOAD split transit trips into peak and base average hourly loads and ULOAD is run for each of the time periods with relevant trip tables, the output information available to URAP consists of assignments of transit person trips by link and line for each of an average peak hour and an average base hour.

URAP allows the user to specify vehicle capacities that can vary by up to 10 types and where each vehicle type can have a different peak and base capacity (allowing for standees in the peak but not in the base). Factors can be used that indicate the number of hours of peak and off-peak service in a weekday, a Saturday, and a Sunday and the number of weekdays, Saturdays, and Sundays operated in the year (thus allowing specification of Saturday or Sunday service on certain public holidays). Other factors can be used to apply to the trip tables loaded on the transit network to convert results to one peak hour and one midday hour. URAP also requests the user to specify the layover at each end of the line, which can be input as a percentage of the one-way trip time or as an absolute number of minutes. In subsequent computations, URAP adds to this the number of minutes required to increase the sum of the one-way trip time and layover to an integer multiple of the headway (to allow the bus to return on the route at the same headway). Thus, if a line operates on a 20-min headway and has a one-way trip time of 57.6 min with layover specified as 10 percent, URAP redefines the one-way trip time as 63.4 min (57.6 + 5.8) and then requires the bus to lay over for a further 16.6 min to reach a multiple of the 20-min headway. Circuity factors are also available.

Among the special reports that URAP offers are the four highest links on each line listed by the node pair (in a directional sense) and provided for each of the selected peaks (a.m. or p.m.) and the midday. These are obtained by reading the loaded legs files from ULOAD and involve no computation. In addition, URAP reports the daily and annual vehicle miles and vehicle hours of travel for the transit system by company; this involves using the line miles and hours from ULOAD, circuity factors (if any) input by the user, the factors for expansion from input trip tables to annual data, and (for vehicle hours only) the amount of layover specified by the user. Because URAP has no information on deadhead time and distance, these are revenue vehicle hours and miles.

The most useful aspect of URAP is the set of service-level alternatives provided. Four scenarios are described: coded, loaded, nominal, and modified. The four scenarios are each accompanied by similar information. Under the coded scenario, the program lists the headways as coded into the network and shows the maximum load, the vehicle requirements for each of the peak and base periods, and the daily vehicle miles and vehicle hours implied by the headway and trip information. If the network was built in UNET, the trip time and distance information will necessarily vary from that produced by the network and the assignment, because of the addition of layover, and any user-specified local circuity. If the network was built by using INET, there may be little or no difference. The numbers of vehicles are calculated taking into account the length of each period. Thus, if there is a bus route that takes 3 hr and 17 min in the peak for a round trip, including layover, and the peak is defined as 3 hr, the vehicle requirements will be 3 hr divided by the headway (because no vehicles can run a second trip). On the other hand, if another route has a round-trip time in the peak of 2 hr and 43 min and a headway of less than 17 min, at least one bus can run a second trip. This is taken into account in determining vehicle requirements. On each line, the vehicle miles and vehicle hours are estimated for each of the two periods selected. The program also prints out the maximum load on the line and indicates whether this represents an overload.

In the loaded scenario, URAP calculates the headways needed to provide sufficient service to fill the buses by using capacities provided by the user for each vehicle type. In this case, five vehicle types can be used, corresponding to the five transit modes allowed in the coding of UTPS networks. Thus, vehicle type 1 corresponds to mode 4, vehicle type 2 to mode 5, and so on. If mode 4 is specified as local bus with a peak capacity (including standees) of 65 passengers, the maximum hourly peak load is divided by 65. The result of this calculation is the number of buses per hour required to service the peak demand. Dividing this number into 60 min provides the peak loaded headway, which is adjusted to the next lowest headway included in the input list by the user. Identical calculations can be performed for the base period or the user can specify that the peak-to-base ratio in the coded headways is to be maintained, irrespective of base loadings. Vehicle requirements and all other statistics are then calculated by using these loaded headways as the basis.

For example, suppose line 17 has a coded peak headway of 10 min, a coded base headway of 20 min, a peak hourly load of 492 passengers, and an off-peak hourly maximum load of 164 passengers, with peak capacity of 65 passengers and base of 48. The peak load requires 7.57 buses per hour, which is approximately an 8-min headway. In the base period, the need is for 3.42 buses per hour, which is an 18-min headway. Therefore, this line will be recomputed to an 8-min peak and 18-min base headway, with all statistics recomputed accordingly. If input headways were only 5, 7, 10, 12, 15, and 20 min, among others, then the 8 and 18 min would instead be replaced by 7 and 15 min as the nearest headways that would provide sufficient capacity to meet the demand. If the maximum loads generate headways that are longer than those coded, the longer headways that are adequate for demand are listed. Suppose line 20 has a maximum peak load of 102 passengers and a maximum base load of 41 passengers, with coded headways of 20 min in the peak and 40 min in the base. URAP will determine that the demand service level is 38 min peak and 65 min base. Assuming that these are the nearest input headways, the line would be recorded to 35 and 60 min.

The nominal scenario changes the vehicle requirements by imposing policy headways whenever a loaded headway is longer than a maximum headway for a line input by the user; the format shown in Table 2 is used. Thus, the user specifies each coded headway and a maximum policy peak headway and maximum and minimum base headways corresponding to each. Typical input information for this is shown in Table 2. Thus, for all lines on which the loaded headways do not violate the policy headways set out by the user, the nominal and loaded data are identical. However, if the loaded data represent a violation of policy constraints, the policy headway is substituted and line statistics are recomputed for the policy headways. Thus, if the 20-min peak headway has a maximum

TABLE 2 Typical Inputs of Policy Headways

Coded Headway (min)	Policy Headways (min)		
	Maximum Peak	Maximum Base	Minimum Base
2	10	10	2
3	10	10	2
4	12	12	2
5	15	15	2
6	15	15	2
7	20	20	2
8	20	20	3
10	20	20	5
12	25	25	5
15	30	30	5
.	.	.	.
.	.	.	.
.	.	.	.
60	60	90	20

base headway specified of 45 min, line 20 in the foregoing example would be reset to 35 min peak and 45 min base, with vehicle requirements, vehicle hours, and vehicle miles recalculated accordingly.

Last, the modified scenario represents changes that can be input by the user on a line-by-line basis. The parameters that the user may override include the vehicle capacity (allowing specification of special vehicle types, such as articulated buses, to serve one or more lines), deadhead time, maximum passenger load, layover time, and circulation time. Also, the user can input short lines and new lines and obtain system statistics for such added lines without the necessity of returning through the simulation process. This addition of new lines does require, however, that the user estimate the maximum passenger load that such a new line would carry without the benefit of a simulation to establish this. The primary benefits of this estimation are to determine the likely effects on fleet requirements of such changes as well as to override some of the automatic recalculations of URAP. For example, a few bus lines may exhibit a spuriously high load that cannot be corrected through a more realistic network description. The recomputation of vehicle requirements, headways, and so on can be overridden by specifying a maximum passenger load on the line that is more realistic and having URAP recompute headways based on this. Special layover times can also be input for short lines, where the percentage layover may result in violations of union rules because of the shortness of the trip time.

URAP has also assembled the necessary data to run a UTPS-compatible operating cost model and is designed to output a disk file that can be used as input to a cost model that uses variables such as vehicle miles, vehicle hours, and peak vehicles. These values are provided on a line-by-line basis, so that line-by-line cost estimates are possible.

USING THE ROUTE-ANALYSIS PROGRAM

The route-analysis program is not a model in the conventional sense, so there is no calibration step involved in its use. The underlying calibration is that of the transit network. The route-analysis program assists the process of network calibration by providing statistics such as peak and base vehicle requirements, daily and annual vehicle miles and vehicle hours of travel, and specific line statistics such as round-trip time and distance, peak passenger load, and location of the peak load point, all of which can be checked against actual system statistics. The detection of significant departures between the actual system and the route-analysis program outputs should lead to identification of problems in the transit network that require correction.

Once the network has been calibrated satisfactorily, simulation runs can be made and URAP can be used to analyze the performance of the system. First, URAP can be used to generate system statistics for the simulation situation that provide a guide to the performance of the system. Loaded bus requirements that are significantly higher than the coded ones signify that the bus system is overloaded, a situation not easily determined from a single figure in standard network assignments. If nominal bus requirements are significantly higher than loaded-bus requirements, this signifies that the policy headways that override demand headways result in a need to provide an excessively high level of service compared with demand. Similarly, if loaded and nominal bus requirements are below those coded, it is indicative that too many buses are being provided for the level of demand or to maintain policy service levels.

On a line-by-line basis, the statistic of peak load on a line is asterisked if the load exceeds capacity. An examination of the table of line statistics reveals quickly on which lines there is an overload, and when the accompanying headways and vehicle requirements for the loaded condition are compared with the coded line, the order of magnitude of the overload is also revealed.

Interpretation of these statistics should, however, be made in conjunction with the transit assignment outputs of line loadings (Report 2 in ULOAD) or in conjunction with URAP Report 5 giving the four maximum load links. Because of the aggregate nature of transit networks and the incidence of connections from zone centroids, it is possible for the loaded network to generate a one-link extraordinary peak load. This load is probably not a real peak and represents rather the result of the aggregation process. Therefore, the loads on the line around the peak-load point should be investigated to determine whether there is a sustained overload (indicating a genuine need to increase capacity) or only a one- or two-link overload that drops off rapidly on either side of the peak-load point. A further use of Report 2 from ULOAD is to investigate the incidence of heavy loadings on the line with a view to defining sublines to take care of the overload situations or to make an underloaded line more efficient without reducing service as drastically as might appear necessary otherwise. These sublines can be tested initially in URAP alone; the proportion of the peak load on the new subline can be defined by using the relative headways of the subline and its parent line to split the load. This will provide some information on the likely savings to be achieved by the short lining, although it will not reveal new transfer patterns and other potential path changes. Subsequently, the sublines can be coded into the network and the entire simulation of transit ridership reiterated. This analysis provides the basis for refining the bus network to provide a more efficient service pattern.

There is a pitfall in the process, however. As in highway-network, capacity-constrained iterations, changes in the service levels to provide more appropriate service will generate changes in the demand levels. Specifically, if URAP indicates that a bus line is overloaded and requires more frequent service, coding of the loaded or nominal headways will result in reduced waiting times for the network paths served by the route. This, in turn, will lead to an increased patronage on the line and will generate a further increase in the peak load. Hence, the loaded or nominal headway will be insufficient to carry the enhanced demand. In the reverse case, a line that is underloaded will have a longer loaded or nominal headway than the coded one. Replacing the coded headway with this demand headway will lengthen the waiting time and reduce demand still further. Stable convergence is unlikely if the path building used in the network is all or nothing, because the subsequent path building will drop paths out of the long-headway lines and add paths that use short-headway lines. Thus, if one continually adjusted headways to match demand levels, all lines that were under capacity to start would theoretically end with the maximum policy headways on them, and all lines that started with overloads would end with high frequencies, probably on the order of 1-min headways or less. Clearly, this is neither logical nor desirable. Use of URAP outputs to adjust the headways is more appropriately to apply about half of the change indicated by the loaded scenario and continue to readjust in smaller increments from this. Such a procedure produces a relatively rapid convergence to an acceptable service level on each line.

CASE STUDY APPLICATION

First, a base-year transit network was constructed to cover all bus service in the six-county Los Angeles metropolitan area. Of necessity, the network was constructed by using the UNET program in UTPS, because when this project began, there was no suitable regional highway network available from which to construct an INET network. The network involved using practically the limiting values of nodes and links in the network and necessitated development of several FORTRAN programs to seek out errors in a systematic fashion and to find and delete unused links and nodes in the network. The final base-year network involved use of over 7,500 nodes and 30,000 links and described a bus network with nearly 2,500 peak-period buses. Over 470 individual bus lines and sublines were needed to describe the network. Detailed statistics were available only from the largest operator in the region the Southern California Rapid Transit District (SCRTD). Therefore, all calibration was performed against the SCRTD portion of the regional network, which consists of 305 of the lines and 2,000 of the peak-time buses.

A number of tests were performed to check the base-year network. Briefly, these checks revealed that no coded lines differed by more than 10 percent from actual values of round-trip travel time and one-way distance, except for a few routes that were identified as having incorrect actual values. Chi-square and Kolmogorov-Smirnov tests were performed between actual and network values of times and distances, and no statistically significant differences were found. Finally, with URAP, the network produced a coded peak-vehicle requirement (PVR) of 1,619 buses for SCRTD and a nominal PVR of 1,871 compared with the actual base-year PVR of 1,848 buses. This discrepancy of 23 buses, or 1.2 percent, was considered to be satisfactory. A summary of the statistics for the base-year network under coded and nominal conditions is shown in Table 3.

The primary purpose of the use of URAP in conjunction with the standard UTPS models in this case study was to refine the background bus network for a proposed long-range future systemwide network that included an initial rail line of 18.6 mi. Initial simulations of the rail and bus network with year 2000 trip estimates from the Southern California Association of Governments (SCAG) provided the statistics shown in Table 4 for the original bus network. The bus operating cost for this network of $435.7 million in 1983 dollars was estimated by using a UTPS-based operating cost model (7) that provided an estimate of $398.5 million for the base-year network. Thus, the increase in the peak-vehicle requirement from 1,871 to 1,895 for SCRTD together with increases in revenue-vehicle miles and revenue-vehicle hours and transit ridership growth from 1,170,000 to 1,924,000 daily trips resulted in an estimated increase in cost of $37.2 million. The issue to be determined was whether the future network could be operated more economically without significant loss of patronage.

TABLE 3 Statistics of the Base-Year Network

Statistical Measure	Value Coded	 Nominal
Peak-vehicle requirement (PVR)		
SCRTD local buses	1,228	1,120
All operators' express buses	420	793
Total SCRTD buses	1,619	1,871
Total systemwide buses	2,278	2,447
Total daily revenue-vehicle hours	32,900	33,000
Total daily revenue-vehicle miles	420,000	444,000
Daily linked passenger trips	1,170,000	1,170,000

TABLE 4 Summary of Changes in PVR by Iteration (SCRTD Lines Only)

Variable	Network Iteration Original	 Second	 Third
Peak coded vehicles	1,775	1,820	1,919
Peak nominal vehicles	1,895	1,858	1,907
Base coded vehicles	1,111	905	977
Base nominal vehicles	985	936	942
Revenue-vehicle miles	97,350,000	95,260,000	96,540,000
Revenue-vehicle hours	7,610,000	7,260,000	7,360,000
Linked passenger trips	1,924,000	1,817,000	1,863,000
Bus operating cost[a] ($)	435,697,000	384,522,000	421,563,000

[a] 1983 dollars.

A series of iterative adjustments was made in the network on the basis of the URAP and ULOAD reports. First, all lines were identified from the URAP outputs that were overloaded in either the peak or the base period. Each such line was examined in the ULOAD reports to determine whether the peak load was of extremely limited duration or was spread over a significant portion of the line. In the latter case, consideration was given to defining a new subline. This resulted in the definition of 64 new sublines, the suggested deletion of 43 lines or sublines, and replacement of the current operation of 23 lines or sublines with one of the new sublines. This was a net decrease of two coded sublines in the entire network, but represented some significant shifts of service. All the proposed changes were submitted for review by the planning staff of SCRTD, after which some of the lines recommended for deletion were restored for policy reasons and 10 of the sublines were either removed or assigned different end points, where it is feasible to turn back buses. Even from this first round of network revisions, the majority of routing changes was greeted with no surprise by the SCRTD staff. Most identified changes were logical in light of present loadings, and the extent of the overloaded line segments that were used to identify sublines corresponded well with known segments of heaviest loading. This provides a further indication that the network possessed a high degree of realism and accuracy.

A measure of the degree to which the network is unable to satisfy demand is the difference between nominal and coded vehicle requirements. Table 4 shows the results of the second and third iterations. (The first iteration is not reported here, because a number of errors were found subsequently in it, and the second iteration provided corrections to this.) From the initial network, it can be seen that the nominal PVR was 120 buses greater than the coded one, whereas the base coded network was 136 buses too great. By the second iteration, not only were the nominal vehicle requirements for both peak and base lower than in the original network, but the differences between coded and nominal had decreased markedly, being 38 buses in the peak and 31 buses in the base period. The third iteration shows maintenance of this improvement, although the differences here are that some lightly loaded lines were returned to a higher service level because the previous adjustments had reduced patronage too far. This shows clearly in the annual cost per daily linked trip (not all of which are on the SCRTD buses). For the original network, this cost is

$226.45, for the second iteration it is $211.62, and for the third iteration it is back up to $226.28. However, the difference between coded and nominal PVRs is now 12 buses, with the nominal PVR being slightly lower than the coded PVR. At the same time, the base-vehicle requirement is overestimated by 35 buses. These changes show a slight overcorrection of the deficiencies in the second iteration and auger well for a stable system at the fourth iteration.

Adjustments were made in these iterations by accepting the URAP-generated nominal headways in those instances where lines were severely underloaded or overloaded and coding about half the change between URAP and the original coded headways in all other cases. The use of about half of the headway change is necessary to dampen out the cyclical shift of patronage from lightly loaded lines and into heavily loaded lines. Even so, the second iteration shows too large a swing to the heavy lines and away from the light lines, and this was modified in the third iteration.

At time of writing, a fourth iteration was being developed to complete the redesign of the background bus system. Even before this, it could be seen that the redesign that was enabled by URAP allowed three iterations to reduce the PVRs, the base-vehicle requirements, and the operating cost, all with a relatively small loss of transit riders. More important, the revisions to the network were easily identified and were lengthy to input only because of the large size of this particular case-study network. This procedure would be efficient for a small or medium-sized network.

The most important results of this analysis are that information is provided to allow a systematic adjustment to be made to the bus system for a long-range planning situation; such an adjustment is not usually feasible. Furthermore, all indications are that the final results will be an increase in the efficiency of the resulting bus system and a reorientation of service to where the greatest demands are.

CONCLUSIONS

A procedure for producing bus system statistics from standard UTPS planning models and how this procedure can be used in conjunction with the UTPS procedures to undertake detailed long-range planning of a bus system have been described. It has been shown that the capability of the procedure to produce data that accurately reflect the base year is considerably greater than that normally associated with aggregate travel-forecasting models. Given the increasing importance of developing planning strategies to contain operating costs for transit systems and comprehensive operating-cost plans for regions contemplating major capital investments in transit, this procedure is an important one that adds a needed dimension to the battery of UTPS models.

A number of subsequent improvements are contemplated for the program, including the development of graphical displays of the ULOAD reports that are used in conjunction with URAP and addition of a capability for URAP to output a modified network file by using the nominal headways or some predetermined fraction of the change between coded and nominal headways. Such enhancements will remove much of the time-consuming portion of the current procedure. This capability to refine bus systems through a long-range route analysis also permits a fairly extensive capability to simulate alternative futures and determine probable directions of service changes that should be planned.

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