Goals for Bus Transit Scheduling

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ABSTRACT

Like other transit agencies, the Southern California Rapid Transit District schedules buses using a peak point constraint on crowding. As a way of clarifying implicit scheduling goals of maximizing seat use while minimizing crowding, two indicators were studied, load factor and standee factor. Riding checks carried out on many lines over an extended period allowed computation of 24-hour averages of these indicators for three types of lines: urban local, suburban local, and express. Weighted linear regressions produced a relation between standee factor and load factor for each service type. Elasticities were estimated to give predictions of increases in crowding due to ridership growth. A scattergram of standee factor versus load factor can be used as a diagnostic tool for scheduling management to indicate which lines should be given attention and improvement or deterioration following schedule revisions. The loci of hour-by-hour values of standee factor and load factor give both manager and scheduler a quick overview of the reasonableness of a schedule. Periods of schedule deficiency are readily apparent.

Transit agencies are attempting to increase service productivity in various ways. Although the scheduling function is usually central to any productivity improvements, traditional scheduling practices may not be well suited to maximizing service productivity.

Scheduling practice is typically based on meeting certain service standards. For the high-volume conditions that are of most interest in this paper, standards are usually expressed in terms of maximum loads at peak points. For peak travel periods, the scheduler arranges for flows of buses that just meet the standard.

The implicit goals of scheduling are to provide the highest quality of service and to use the least amount of resources. These goals are expressed in terms of simple measures of quality and productivity. Relationships between these measures are explored, and a means of problem identification is described.

TRADITIONAL LOAD STANDARD

The Southern California Rapid Transit District (SCRTD) has no explicit objective function for scheduling but, like other transit agencies, uses a load standard or crowding constraint. The official statement of loading standards is

> In order to provide an accessible and dependable transit system. . . . All parts of the transit system should . . . have adequate capacity for safety and to attract and keep riders.
>
> (1) Loading ratios for individual lines should not exceed 140% measured for the peak 20 minutes at the maximum load point.
> (2) Loading ratios should not exceed 100% for base periods and evenings.
> (3) Loading ratios for long distance freeway and busway services should not exceed 100% measured for the peak half-hours.

Such a load standard, by focusing on extreme situations, diverts attention from the range of normal operations. Only 30 percent of the bus trips reach a maximum load that exceeds the seating capacity, so the other 70 percent tend to be disregarded. Even within the 30 percent, inconsistencies abound. Two lines could just meet this standard, yet one could have standees for 3 min of each trip and the other could have standees for 20 min. The policy is addressed only to what happens at a peak point. If crowding occurs elsewhere than at a declared peak point, it may be ignored.

INDICATORS OF SERVICE PRODUCTIVITY AND QUALITY

Even though the underlying goal of scheduling has always been to arrange buses in such a way that the least resources are used to produce a given level of service, it is not clear that the usual constraint-based practices are likely to lead to optimum productivity. Further, these practices scarcely address the quality-of-service issue.

What seemed to be needed was a way of expressing the goals of scheduling in terms of indicators that would tell how well a bus line is scheduled overall--over the entire route and throughout the day.

If the objective is to maximize the use of seats while minimizing crowding, the simplest indicators of use and crowding are load factor and standee factor, respectively, defined as

L = load factor = passenger-miles/seat-miles

S = standee factor = standee-miles/passenger-miles

L is a reasonable measure of productivity. Availability of a seat is generally regarded by the rider as a paramount measure of service quality. Therefore, the standee factor is assumed to be a good (inverse) representation of service quality.

EXPLORATION OF THE INDICATORS

Obviously, these indicators are not independent of each other. In the case of a single bus at a single instant of time, S is a deterministic function of L. There are no standees until all seats become full, at which point $L = 1.0$ and $S = 0$. Then the standee factor rises asymptotically toward 1.0 according to

$$S = (L - 1.0)/L$$

until the load reaches the physical limit of crowding. For a 40-ft bus with 43 seats the limit is around $L = 2.5$.

For scheduling, interest is less in instantaneous values of S and L than in averages: over a bus trip, for a stream of buses, or for a bus line operating over some period of time. Averaged over time and space, the dependence of S on L is statistical not deterministic.

For a typical bus trip, the range of possible values of S and L is much smaller than the range of instantaneous values. The load factor will normally be much less than 1.0 because it is an average of a load that varies as the bus travels along the route. The standee factor will not be close to the maximum attainable instantaneous value because there is usually a considerable excess of seats near the ends of the route. However, because all standee-miles are accounted for, S will be greater than zero if there is any standing anywhere along the route.

Accordingly, the range of (L,S) combinations for 1 hr of line operation would be smaller than the range for single bus trips, and the range for 24 hr of operation would be smaller still. The expected ranges would be somewhat as shown in Figure 1. With each successive level of aggregation, the range diminishes.

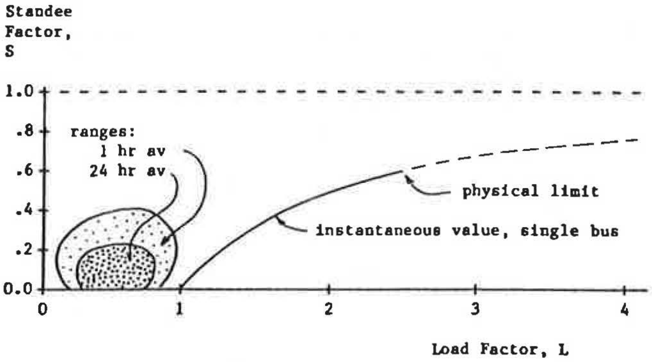

FIGURE 1 A priori relationship of L and S.

The intent of this study was to quantify relationships between the two indicators L and S. Is there a clear functional relationship? How would the relationships vary with service type? How does growth of ridership affect crowding?

The Data

With a computer it is relatively simple to account for all passenger-miles, seat-miles, and standing-miles, wherever they occur. Ride checks are the source of the data. In a ride check, a checker notes how many people get on and off at each stop. The number of people on board between stops is obtained by subtraction of cumulative totals. If the checker knows the distance between stops, seat-miles and passenger-miles can be accumulated, as well as standee-miles. Ride checks are done routinely at SCRTD and at most other transit properties for purposes of planning and scheduling.

The software developed at SCRTD moves stop by stop through the record for each trip, accumulating vehicle-miles, passenger-miles, and the excess of passengers over seats. These numbers are aggregated by line and by direction, but segregated for each hour of the day. The indicators L and S are then tabulated by direction for each hour and for the full service day, stop-by-stop and for the full route.

It should be noted that data obtained from riding checks tend to understate standee factors, because service is known to operate more regularly when it is being monitored. This is likely to cause a moderate but consistent bias.

Analysis

Analyses of the relation of S to L were based on data aggregated to the line level. Because management overview is the primary concern here, 24-hr aggregates of L and S are used, with each direction of the line treated as a separate case. In other words, each case or data point consists of a 24-hr average load factor and a 24-hr average standee factor representing a single line in one direction on a weekday.

Differences Among Service Types

There are three basic types of service at SCRTD: urban local, suburban local, and express. Regressions were carried out separately for each type, with the cases weighted by size of line, expressed in seat-miles, to get a truer reflection of the system as a whole. The results are given in Table 1. The coefficients of determination (r^2) are not very high, yet scatterplots appear to indicate a linear relationship between L and S.

TABLE 1 Coefficients of Regression Lines, $S = a + b\,L$

Line Type	Cases	a	b	r^2
Urban local	74	−2.077	.1535	.263
Suburban local	124	−1.859	.1344	.629
Express	60	−3.318	.1522	.476
All	258	−2.450	.1512	.552

The regression lines are plotted in Figure 2. Also shown are rectangles representing the ranges of the variables for each line type, as well as dots on the regression lines showing the mean load factor values.

Urban local and express buses are scheduled for the demand, so the load factors are higher than are those for suburban local buses. Because express service usually has a flatter load profile, it can be scheduled closer to a full seated load over more of its length. This allows a higher L relative to S. On the other hand, the policy is not to have standees on express services, ostensibly because of safety considerations in freeway operations. As will be seen, scheduling for a load factor anywhere near 1.0 will result in standees, unless patrons are prohibited from boarding when there are no seats available.

It might be of interest to note that hourly averages of L can be as high as 90 percent for urban local service and 110 percent for express service. Hourly highs of S are 20 percent for urban local service and 18 percent for express service.

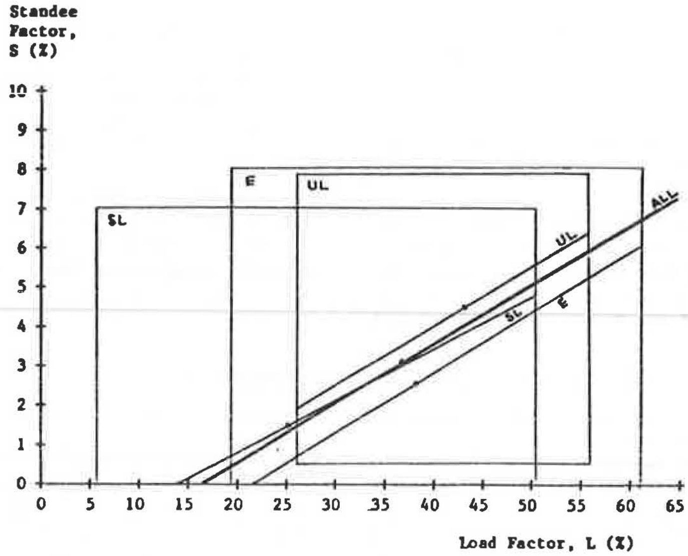

FIGURE 2 Regression lines for various services.

Predicting Increases in Crowding

At the system level, how much would crowding (i.e., standing) increase as ridership rose due to a fare decrease? This can be answered in terms of elasticities of crowding with respect to ridership levels, calculated for the system average or for the averages of the component service types:

$$\text{elasticity} = e = (\Delta S/S)/(\Delta L/L) = (\text{slope of the regression line}) \times(\bar{L}/\bar{S})$$

Calculated values are given in Table 2. This is called the cross-sectional estimate.

One way to test the cross-sectional estimation of elasticity is to compute actual percentage increases in L and S over a period of time. From the 258 cases used here, 170 were selected in which the checks could be matched with earlier checks taken in the year before the fare reduction. Because the aggregate of this subset would not have exactly the same characteristics as the larger set from which it is drawn, cross-sectional estimates of elasticity were calculated for before and after versions of the subset. The elasticities were 3.4 and 2.9, from the pre-decrease data and the post-decrease data, respectively. These could then be compared with the actual elasticity of the subset. Calculated directly as percentage growths in overall S relative to percentage growth in L, the actual elasticity was 2.8.

TABLE 2 Elasticities of Crowding with Respect to Ridership

Service	No. of Cases	Mean Load Factor L (%)	Mean Standee Factor S (%)	Slope of Regression Line	e
Urban local	74	43.2	4.55	.153	1.46
Suburban local	124	25.1	1.41	.133	2.37
Express	60	37.9	2.44	.152	2.36
Overall	258	36.4	3.06	.151	1.80

If the actual elasticity (i.e., time related) is lower than the prior cross-sectional estimate, it might be concluded that the lines involved have improved in productivity more than they have degraded in service level. (A zero elasticity would imply that increased loadings were accommodated without increased crowding.) The precision of these estimates is probably not sufficient to allow any such conclusions to be drawn, but the consistency of the numbers is heartening.

USE OF INDICATORS FOR SCHEDULING

How can this information be used to manage the scheduling function, to bring about improvements in economy and quality of service? For the most advantageous use of scheduler manpower, the load factor-standee factor combination of indicators is used at five levels of aggregation to progressively narrow the search for schedule revision opportunities. These aggregation levels are

1.	All lines composite, whole day	Used only to indicate whether the scheduling process is improving over long periods of time
2.	All lines composite, by hour	Provides a norm or frame of reference for individual lines
3.	Whole line, single direction, whole day	Provides an overview of line abnormalities and indications of need for new schedules
4.	Whole line, single direction, by hour	Tells the scheduler which part of the schedule is causing overload problems and where a detailed analysis is needed
5.	Stop-by-stop, single direction, by hour	Tells the scheduler which portions of the lines are overloaded, especially as an indication of desirability of deadhead trips or short turns

It will be recalled that the coefficient of determination for the relationship between S and L was not particularly high. One inference that may be drawn is that the service is not as consistently scheduled as it could be. A corollary is that the poor-performance lines might be rescheduled to more nearly match the high-performance lines.

Consider the scattergram of S versus L shown in Figure 3 with the regression line displayed. If average bus lines are on the regression line, poorer-than-average lines are above it. In other words, their standee factors are too high for their load factors. If a schedule is improved in quality, the next check should show a migration toward or even across the regression line.

If all lines were being improved, the regression line itself would move to the right. As a diagnostic tool for management, the scattergram indicates the lines that should receive the most scheduling effort.

The scattergram can be used to infer potential productivity improvements due to improved schedules. If average load factor is an indicator of productivity and standee factor is an (inverse) indicator of level of service, horizontal rightward shifts of points on the scattergram imply a pure productivity improvement without a loss in level of service.

The scheduler can use the hour-by-hour data for a single line and direction to see where to focus on specific problems. Figure 4 shows the loci of 1-hr points as well as the 24-hr-average point for a fairly typical heavy line. The urban route regression line is superimposed for reference. The loci indicate that the schedule is reasonable in the sense that the highest standee factors are in the peaks and the most crowded peak is in the morning. However, the location of the 24-hr-average point indicates that some improvement in the schedule is possible, either by bringing down the standee factor or by increasing the load factor.

The scheduler might choose to look for the reasons for such a high standee factor in the morning peak. For that she would make the traditional analyses of point check data at peak points and turn-back locations or look at specific trips in the line profile data.

GENERIC ACTIONS

The approach to schedule evaluation described here can be regarded as a way of looking for the most extreme schedule deficiencies. Alternatively, it can be viewed as a way of searching for opportunities to apply generic actions (1). If quality can be represented by the likelihood of finding a seat on the next bus to arrive and productivity by the percentage of seats filled, adroit scheduling can reduce

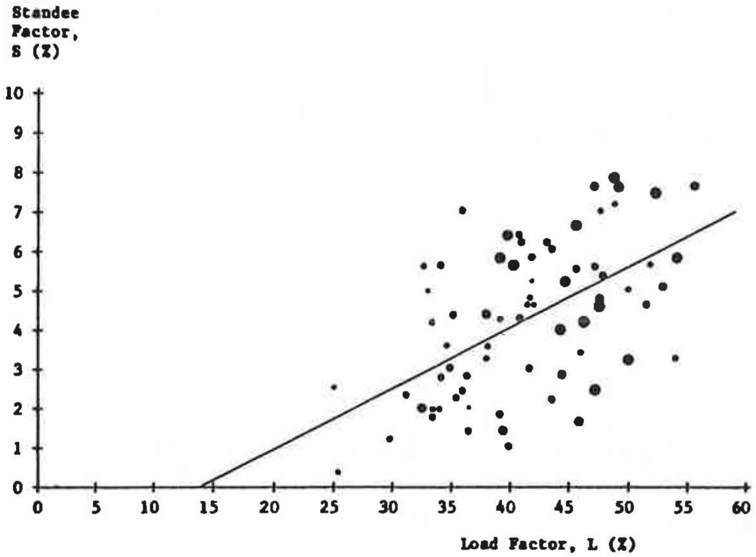

FIGURE 3 Scattergram of urban local lines.

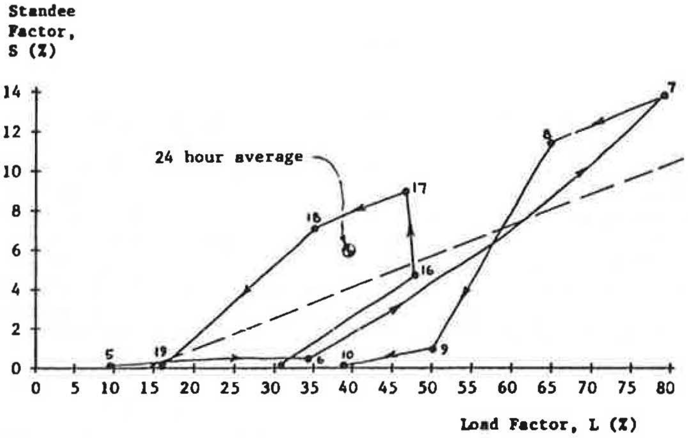

FIGURE 4 Loci of (L, S) for a single line in a single direction over a 24-hr period.

the chance of not finding a seat while bringing the average percentage of seats filled closer to 100.

Examples of generic actions that can reduce standee factor without reducing load factor are shortlining, partial deadheading, and headway offsets.

By shortlining, or running buses over only a segment of the route, capacity can be shifted from a portion of a line on which the seats are seldom filled to another segment on which people frequently must stand.

Headway offsets are a way to even the loads on successive trips, where one trip regularly tends to have standees and a succeeding trip is regularly light.

Partial deadheading is a technique for saving buses by running a fraction of the buses without passengers (and consequently faster) in a light direction, in order to add a few trips in the heavy direction. Correctly done, this raises the overall load factor and reduces the standee factor.

CONCLUSION

The intent of this study was to gain a better understanding of two indicators of scheduling performance before setting quantitative goals. Something has been learned about the current system. Considering the common perception that the system is overcrowded, the 24-hr averages of both load factor and standee factor are surprisingly low. The load and standee factors clearly show how overcrowding is a matter of time of day and line segment.

In setting goals for scheduling, what is subject to scheduler influence must be borne in mind. Although the scheduler should endeavor to increase load factors, she typically has little direct control over them--they are more directly a result of budget balancing. Within the overall load factors, however, schedulers should attempt to reduce standing as much as possible.

With this in mind, an informal goal of scheduling has been formulated on the basis of the elasticity results of this study. The goal is to hold rises in standee factor to less than 1.6 percent for every 1 percent rise in load factor. A similar goal statement could be made for declining load factors, but a decline is unlikely to occur in the face of pressures for greater productivity.

The transit industry knows relatively little about how well it could do. Quantifying how well it is doing now is just a first step toward determining what is possible. What is needed next is a concerted attempt to push the state of the art of service design and operation. This could give a better indication of just how high the load factors could be in combination with low standee factors.

REFERENCE

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Computer Application for Determining Bus Headways and Timetables

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ABSTRACT

One component of an extensive program to develop applications for bus automatic data collection systems (ADCSs) is presented. Current procedures for determining bus timetables are reviewed, and alternative methods for creating timetables using passenger load data are proposed. The major objectives set forth are to evaluate timetables in terms of required resources; to improve the correspondence of bus departure times with passenger demand; to allow headway-smoothing techniques (similar to what is done manually); to integrate different headway-setting and timetable construction methods; and to permit direct bus frequency changes for possible exceptions (known to the scheduler), which do not rely on passenger demand data. The final product of the study consists of a set of computer programs that perform (a) conversion from the bus property mainframe files to an adequate input file, (b) analysis of four methods for setting bus headways, and (c) creation of alternative public timetables at all the route time points. These programs are tested on a heavily traveled bus line in Los Angeles, and the derived alternative frequencies and timetables are interpreted and discussed.