

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. Al-

though 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

1. N.H.M. Wilson and S.L. Gonzalez. Methods for Service Design. In *Transportation Research Record 862*, TRB, National Research Council, Washington, D.C., 1982, pp. 1-9.

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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.

Passenger demand at the route level is generally ascertained at one or more selected stops along the route where the bus carries its heaviest loads (point check). A more comprehensive method is based on load profile and running time information gathered along the entire length of the bus route (ride check). Point checks are typically conducted several times a year; ride checks are often performed only once or twice during the year.

The methods used by bus properties worldwide are commonly based on the following service standards: (a) adequate space will be provided to meet passenger demand and (b) an upper bound is placed on the headway to assure a minimum frequency of service (policy headway). The first requirement is adequate for heavy ridership hours (peak periods), and the second for light ridership hours. The first requirement is usually met by the peak load factor method--the required number of buses is obtained by dividing the maximum observed passenger flow by a load standard (desired occupancy, number of seats). The second requirement is met by establishing policy headways (maximum allowed headways) that usually are 30 or 60 min.

Several researchers have approached the bus headway determination problem through mathematical programming techniques (1-3). However, these mathematical programming models have not been generally adopted by transit schedulers because the models are not sensitive to a great variety of system-specific operational constraints. For example, they cannot simultaneously determine evenly spaced headways and unevenly spaced headways for situations involving scheduling exceptions.

#### PREPARATION OF TIMETABLES

In current practice schedule changes are made using a mix of manual and computer-generated reports. The use of computerized reports has been established in many large bus properties [e.g., Southern California Rapid Transit District (SCRTD) in Los Angeles, Toronto Transit Commission in Toronto, EGGED in Israel]. The procedure employed by SCRTD to develop timetables will be used as an example. On the basis of ride- and point-check data, the following steps are performed by the SCRTD scheduling department:

1. Running times are established for each route by time of day (using the most recent ride-check data).
2. Calculated bus speeds are examined for each time period and route segment in order to correct special cases of speeding up and slowing down of buses (e.g., drivers may speed up toward the end of the route in order to extend their layover time).
3. Headways are determined at the peak point. This is usually the time point at which maximum passenger flow is observed; a time point is generally a bus stop at a major intersection or facility that appears on the public timetable.
4. Initial departures (passage) times are set at the peak point.
5. Departure times are set at all route time points including the departure and arrival terminals by using the established running times and the headways at the peak point.
6. Departure (passage) times are adjusted at the peak point to take into account two additional considerations: trips with short turns and the vehicle block construction procedure.
7. The final route timetable is completed.
8. After the updating of the schedule, the changes (or the new timetable) are marked on the

timetable print instruction sheet that is transferred to marketing.

The scheduling departments at various bus properties including SCRTD are seeking improvements at three different levels:

- Elimination of manual steps,
- Improved accuracy, and
- Cost saving and productivity gains.

The first improvement is anticipated to take place in the relatively near future, due to the acceptance of a computer in the scheduling department. However, it is understood that, even with the computerized process, many decisions will be made on the basis of the scheduler's judgment (e.g., the development of timetables for periods with special activities such as sporting events). The second improvement is directly related to the data collection methods. With greater use of an automatic data collection system (ADCS), it is anticipated that this improvement could be easily attained. The third improvement is related to new and more efficient scheduling methods; the data collected will provide a reliable basis for the scheduler's decision. For example, the ADCS might provide the required data, but, without appropriate statistical models, the data would be meaningless. The statistical models should accurately reflect the variations of both the passenger demand and the vehicle performance measures. [For a statistical analysis of bus running time data see Ceder (4).]

This study provides alternative methods for determining bus timetables using passenger load data. The major objectives set forth are (a) to evaluate timetables in terms of required resources; (b) to improve correspondence of bus departure times with passenger demand; (c) to allow headway-smoothing techniques (similar to what is done manually); (d) to integrate different headway-setting and different timetable construction methods; and (e) to permit direct bus frequency changes for possible exceptions (known to the scheduler), which do not rely on passenger demand data.

#### METHODS FOR SETTING BUS HEADWAYS

Earlier work (5), which is strongly related to the procedures described in the following sections, is presented and clarified in this section. This early work describes four alternative bus frequency determination methods to fulfill two major objectives:

- Setting of bus frequencies both to maintain adequate service quality and to minimize the number of buses in the schedule and
- Efficient allocation of resources to gather passenger load data.

The first objective is to evaluate alternative methods of determining bus frequencies in conjunction with saving resources. The second objective compares the costs and benefits of information obtained from point checks and ride checks. The ride check provides more complete information than the point check, but it is more expensive because either additional checkers are needed to provide the required data or an automatic passenger counter is used. There is also the question of whether the additional information gained justifies the expense. Certainly, for bus properties that have ADCS this question is also relevant because only part of the overall fleet will be equipped with ADCS. The ADCS may be rotated among several groups of routes, de-

pending on whether it is worthwhile to gather point-check as opposed to ride-check data.

The four frequency determination methods in Ceder (5) can be summarized by the following four equations:

- Two point-check methods for time period  $j$

$$\text{Method 1: } (\text{Frequency})_j = (\text{Load at the daily maximum load point})_j / (\text{Desired occupancy})_j \quad (1)$$

$$\text{Method 2: } (\text{Frequency})_j = (\text{Load at the hourly maximum load point})_j / (\text{Desired occupancy})_j \quad (2)$$

- Two ride-check methods for time period  $j$

$$\text{Method 3: } (\text{Frequency})_j = \text{MAX} \left\{ \left( \frac{\text{Area under the load profile in passenger-km}}{(\text{Desired occupancy})_j} \times (\text{Route length}) \right) / \left( \frac{\text{Load at the hourly maximum load point}}{\text{Bus capacity}} \right) \right\} \quad (3)$$

Method 4:  $(\text{Frequency})_j$  is the same as in Method 3 but is subject to a constraint that limits the length of the route over which the load may exceed the product of  $(\text{Frequency})_j \times (\text{Desired occupancy})_j$ .

Note that hourly or other time periods that coincide with  $j$  may be used in Equations 2 and 3 and that passenger-miles may be used instead of passenger-kilometers in Equation 3.

The first method is based on data gathered at one point during the day. This point is usually determined from old ride-check data or from information given by a mobile supervisor. It represents the stop with the heaviest daily load along the route. The second method is based on the maximum load observed in each time period (usually an hour) instead of the whole day. Certainly, it is less costly and more convenient to station an observer (when the data are collected manually) at one point during the entire working day than to assign observers to different points every time period. When ride-check data are available (collected either manually or by ADCS), the program established in Ceder (5) compares Methods 1 and 2, and, as a result, the scheduler can decide about the appropriate point-check procedure.

The third method is based on load profile information. The load profile is plotted with respect to the distance traveled from the departure point. Thus, the area under this curve serves as a productivity measure in passenger-kilometers (or passenger-miles). This area divided by the route length is the average load as opposed to the maximum load in each period  $j$  in Method 2. Method 3 also guarantees, in an average sense, that the passengers on board on the maximum load segment will not experience crowding above the given bus capacity (number of seats plus maximum allowable standees). This method is useful for situations in which the scheduler wishes to know the number of bus runs that can be saved by raising the desired occupancy standard without incurring overcrowding. However, Method 3 can result in unpleasant travel for an extended distance over which the average load is above the desired occupancy. To control this undesirable situation, it is possible to establish a level of service criterion by restricting the total route distance that has loads greater than the desired occupancy. This is in essence Method 4.

A Programming Language, Version 1 (PL/1) program has been written for all four methods. This program compares the results of Methods 1 and 2 and uses a load profile density measure in a preliminary examination of the point- and the ride-check methods. The investigation of the load profile density measure

suggests the use of a point-check procedure for relatively flat profiles and a ride-check procedure otherwise (5). The program calculates the bus frequency for each time period and for each method. Three criteria are selected for Method 4: 10, 20, or 30 percent of the route length is allowed to have an observed load exceeding the desired one (these criteria can obviously be varied).

#### ALTERNATIVE TIMETABLES

There is always a trade-off between increasing passenger comfort and reducing the cost of service. Bus schedulers certainly understand the need to accommodate the observed passenger demand as well as possible. However, at the same time, their effort is also directed to the minimization of vehicle and driver costs. Different bus properties use different scheduling strategies based on their own schedulers' experience. As a result, it is unlikely that two independent bus properties will use exactly the same scheduling procedures at the detailed level. In addition, even at the same bus property, the schedulers may use different scheduling procedures for different groups of routes. Consequently, there is a need, when developing computerized procedures, to supply the schedulers with alternative schedule options along with an interpretation and an explanation of each alternative. Undoubtedly, it is desirable that one of the alternatives coincide with the scheduler's manual procedure. In this way, the scheduler will be in a position not only to expedite the manual tasks but also to compare his methods with others in terms of the trade-off between passenger comfort and operating cost.

Current timetable determination procedures provide the basis for establishing the spectrum of alternative timetables. Three categories of options can be identified: (a) selection of type of headway, (b) selection of a method or combination of methods for the setting of frequencies, and (c) selection of special requests. These three groups of options are shown in Figure 1. A selected path in this figure provides a single timetable. Hence, there is a variety of timetable options.

In the first category, alternative types of headway are considered. An equal headway simply means constant time intervals between departures in each time period, or evenly spaced headway. A balanced headway refers to unevenly spaced headways in each time period so that the observed passenger loads on all buses are similar. A smoothed headway is simply an average headway between the equal and balanced headways. It is an option in cases in which the available data are not sufficient for concrete conclusions about balanced headways but in which the scheduler believes that equal headways will result in significantly uneven loads. Such uneven load situations occur around work and school dismissal times and for trips with short turns. The theoretical work and the detailed procedures for this category appear elsewhere (6).

In the second category it is possible to select different frequency or headway determination methods. This category allows for the selection of one method as well as combinations of methods for different time periods. The methods considered, indicated in Figure 1, are the two point-check and the two ride-check methods described in the first section. In addition, there might be procedures used by the scheduler that are not based on data but rather on observations made by the road supervisors and inspectors as well as other sources of information.

The third category allows for special scheduling requests. One characteristic of existing transit

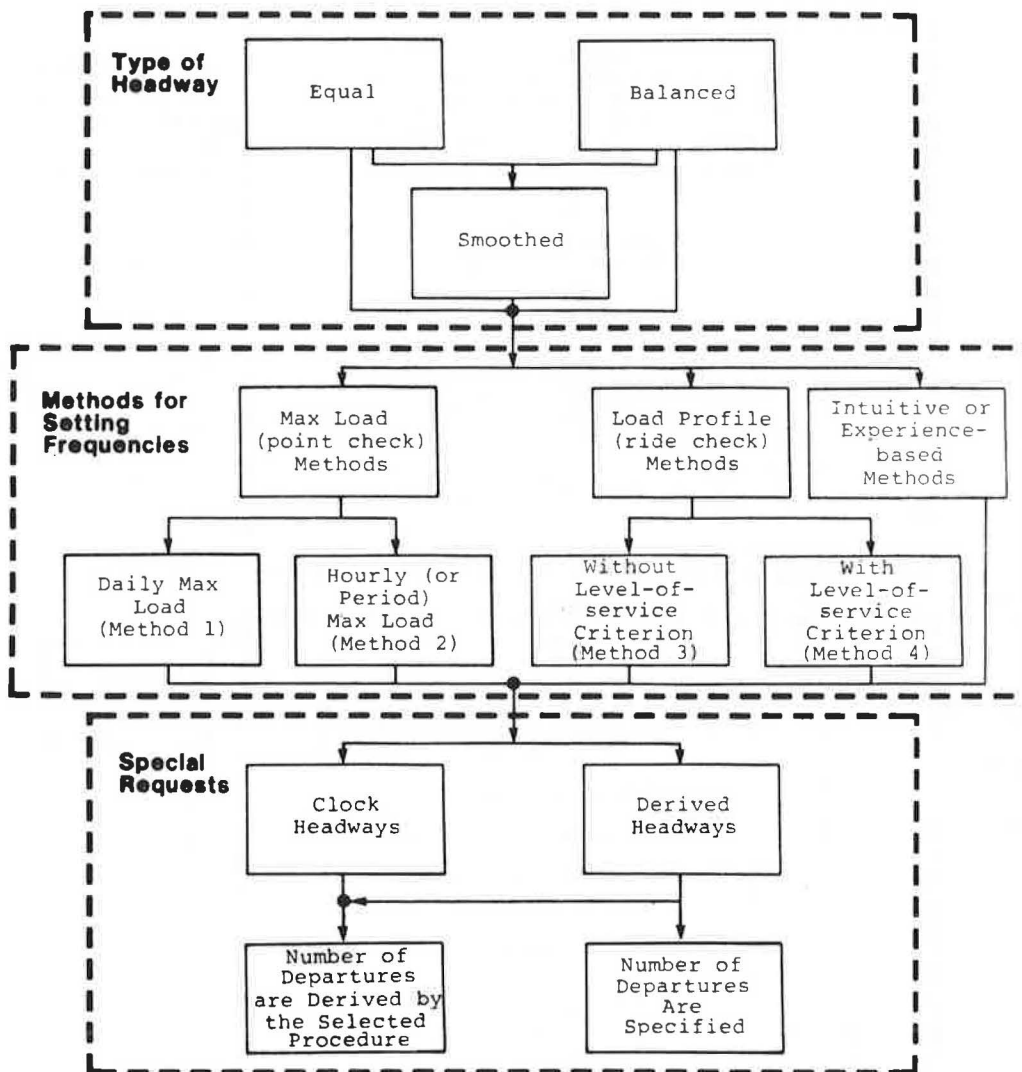


FIGURE 1 Alternative timetables.

timetables is the repetition of departure times, usually every hour. These easy-to-memorize departure times are based on "clock headways" of 1, 2, 3, 4, 5, 6, 7.5, 10, 12, 15, 20, 30, 40, 45, and 60 min. Note that schedules do not generally consider that headways of less than 6 min influence the timing of passenger arrivals at a bus stop. However, for a general timetable determination procedure, there might be peak periods in which the headways are less than 6 min but need to be marked explicitly on the timetable.

The second possible special request is to allow the scheduler to prespecify the total number of bus departures during a time period. This request is most useful in crises in which the scheduler needs to supply a working timetable for operation on the basis of tightly limited resources (buses or drivers, or both). By using his intuition and controlling the total number of departures, the scheduler may achieve better results than by simply dropping departures without any systematic procedure. Also, there might be cases in which the scheduler would like to increase the level of service by allowing more departures. Such situations occur when there is a belief that passenger demand can be increased by providing improved (more frequent) service. Certainly, the latter special request can also be approached through varying the desired occupancy

values, and it is up to the scheduler to decide whether to control the passenger loads or the number of departures, which directly governs the required fleet size.

It is important to emphasize that not all the paths in Figure 1 regarding clock headways are meaningful. Selection of balanced or smoothed headways cannot be performed if there is a clock headway constraint. Also, as shown in Figure 1, the number of departures cannot be specified for clock headways due to the specific time restrictions on those headways.

#### COMPUTER PROGRAMS AND TEST RUNS ON AN SCRTPD ROUTE

In this section the product of the analysis, which demonstrates that all the study objectives set forth in the first section are fulfilled, is discussed. The product is a set of computer programs that perform

- Conversion from the bus property mainframe files to adequate input files,
- Analysis of four methods for setting bus frequencies, and
- Creation of a public timetable at all the route time points.

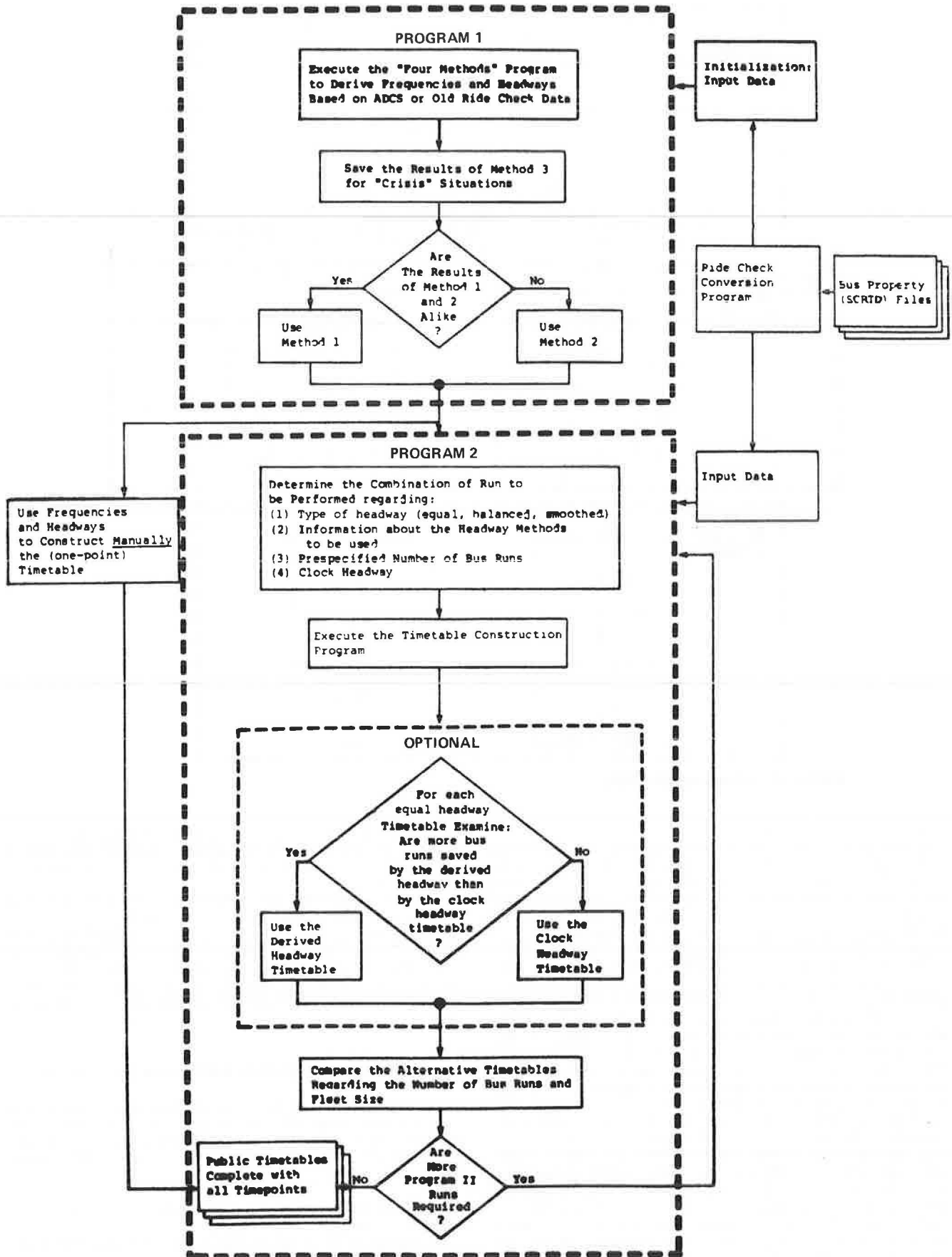


FIGURE 2 Flowchart of Program 1 (setting alternative frequency and headways) and Program 2 (constructing alternative timetables).



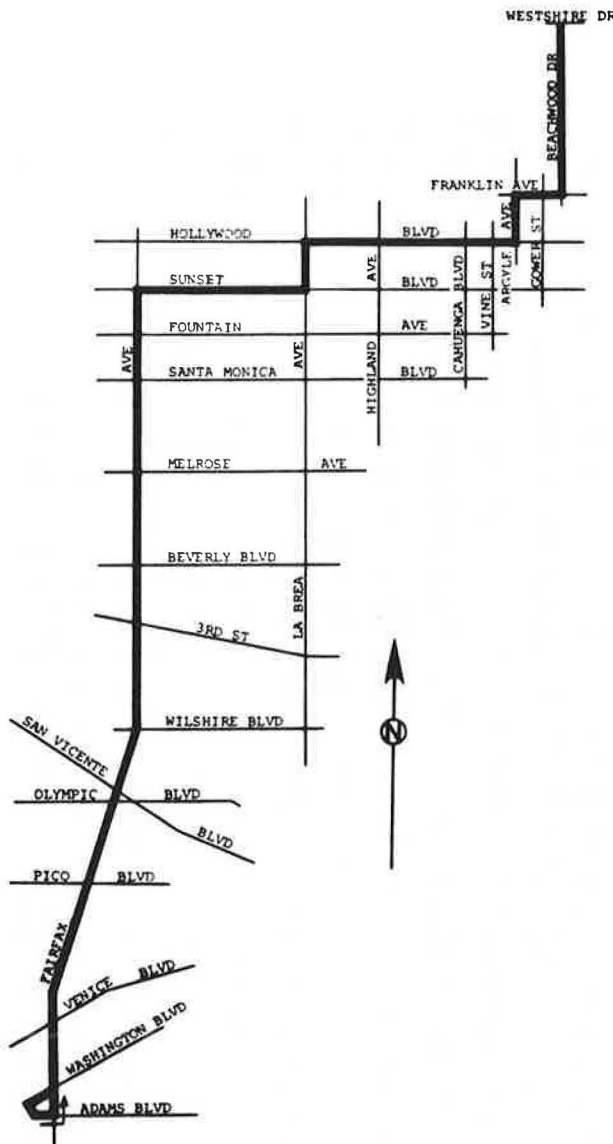


FIGURE 3 Geometry of SCRTD Line 217.

Recent ride-check data from SCRTD Line 217 are used to demonstrate the programs. The use of real-life data provides the possibility of studying the full range of the programs' implementation potential.

#### Description of the Programs

The construction of alternative timetables is mainly based on two PL/1 programs:

- Program 1--setting frequencies and headways by four methods and
- Program 2--setting alternative bus departure times at the base stop (maximum load point) and all the route time points.

The basic user input to Program 1 consists of

- Route (line) number;
- Bus type;
- Direction of travel;
- Bus capacity (number of seats plus maximum allowable standees).

- Number of time periods;
- Name of each stop (or time point);
- Distances between adjacent stops (or time points) along the route;
- Number of observed departures in each time period;
- Minimum frequency (policy headway in terms of the minimum required number of buses in each time period);
- Desired occupancy (load factor or load standard) in each time period; and
- Loads between each two stops (or time points); averages are preferred in each planning period (i.e., Monday through Friday, Saturday, Sunday and holidays, and exceptions).

The basic input to Program 2 consists of

- Description of time periods including their length;
- Round-trip time including layover and turn-around times in each time period;
- Determined (noninteger) frequencies from Program 1 including possible user changes and additional frequencies (e.g., inserted by the scheduler) for each time period;
- Running times from the base stop (usually at the daily maximum load point) to each time point that appears on the public timetable (negative times are assigned to time points that precede the base stop);
- Observed average departure (or passage) times for each individual bus at the base stop;
- Observed average headway for each bus; and
- Observed average loads for each bus based on the selected frequency setting methods (e.g., load at the daily maximum load point for Method 1, load at the hourly maximum load point for Method 2, and load profile for Methods 3 and 4).

A schematic overview of the computerized system is shown in a flowchart in Figure 2. This flowchart, aside from describing the programs, advises the user on the various available options. It is anticipated that initialization will be at the mainframe computer files of a bus property. A conversion program has been written to prepare adequate input data for Programs 1 and 2. This program assumes that ride-check data are available in the bus property files.

The analyses made by Program 1 are explained elsewhere (6) and further interpreted by Ceder (5). In Program 2 the user can request various alternative timetables according to the options shown in Figure 1. For each computer run using Program 2, the user simply keypunches requests as follows:

1. Type of headway:
  - 1 for equal headways,
  - 2 for balanced headways, and
  - 3 for smoothed headways;
2. "Number" of methods to be used (among the inserted frequency-setting methods);
3. For each method used the user specifies
  - Method "number,"
  - Time period "number" in which to start using the method, and
  - Last time period "number" to use the method in the considered combination (i.e., the same method can be used several times for different time periods and each combination must be specified);
4. Clock headway
  - 0 for not required and
  - 1 for required; and

TABLE 1 Initial Data for Line 217 (northbound)

TIME INTERVAL	NUMBER OF PASSENGERS PER INTERVAL																									TOTAL
	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900	3000	
NO OF BUSES	6	10	8	8	8	7	8	8	8	10	8	9	6	5	3	3	2	2	2	2	2	2	2	2	2	
MINIMUM NO OF BUSES	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
RECOMMENDED NO OF PASS	60	70	70	60	50	50	50	50	50	60	70	70	60	60	50	50	50	50	50	50	50	50	50	50	50	
DIST ST NAME																										
O 18 ADAMS / WASHINGTON	13	27	115	24	11	11	8	4	10	9	18	23	18	8	2	3	2	5	1	308						
O 26 FAIRFAX / ADAMS	21	68	148	39	16	27	26	8	16	19	24	38	23	12	3	7	2	5	1	503						
O 27 FAIRFAX / WASHINGTON	22	89	180	48	22	32	29	15	23	20	35	40	23	15	3	8	6	5	1	596						
O 28 FAIRFAX / APPLE	25	101	163	51	26	34	29	16	23	23	40	45	24	14	3	8	6	5	1	637						
O 27 FAIRFAX / VENICE	29	112	183	53	37	43	37	22	26	34	60	51	32	19	3	8	9	5	2	765						
O 27 FAIRFAX / VENICE F	37	124	217	84	52	44	51	39	36	48	78	60	37	21	7	8	10	6	3	961						
O 24 FAIRFAX / 18TH	40	119	188	83	51	45	52	39	37	57	78	61	37	20	6	8	9	6	3	939						
O 24 FAIRFAX / AIRDROME	40	121	192	89	52	49	54	42	38	60	77	65	35	19	8	11	9	7	3	981						
O 24 FAIRFAX / PICKFORD	45	151	195	94	48	50	54	42	40	60	78	67	35	19	9	12	9	7	3	1018						
O 24 FAIRFAX / SATURN	48	167	211	97	58	50	55	45	39	60	73	63	31	18	9	13	9	7	3	1056						
O 24 FAIRFAX / PICO	56	217	246	116	83	78	84	95	73	94	105	97	49	30	11	12	14	8	4	1472						
O 26 FAIRFAX / PACKARD	59	228	252	120	91	80	87	98	76	96	105	98	47	30	11	12	15	8	4	1517						
O 26 FAIRFAX / WHITWORT	63	250	257	125	98	87	90	100	78	96	104	98	53	31	14	12	15	9	4	1584						
O 00 FAIRFAX / OLYMPIC	59	244	275	130	108	98	103	120	99	86	122	99	54	38	16	12	18	10	5	1696						
O 24 OLYMPIC / OGDEN	59	332	278	152	123	99	116	142	103	104	129	115	64	39	16	12	18	10	5	1916						
O 22 FAIRFAX / SAN VICE	70	355	325	171	144	124	141	181	142	149	151	134	73	40	17	15	19	12	6	2269						
O 24 FAIRFAX / 8TH ST	86	357	330	175	150	128	145	188	164	156	170	158	77	42	18	16	19	13	6	2378						
O 29 FAIRFAX / WILSHIRE	54	363	349	236	288	250	354	356	342	397	382	343	190	91	40	24	36	18	8	4121						
O 29 FAIRFAX / 6TH ST	55	369	351	238	291	257	363	365	347	398	386	343	189	94	41	27	34	18	8	4174						
O 29 FAIRFAX / DREXEL	54	376	355	234	291	258	381	378	350	398	391	339	191	93	42	27	34	18	9	4219						
O 29 FAIRFAX / 3RD ST	48	401	370	234	261	258	338	381	367	422	454	367	205	101	56	37	38	19	9	4356						
O 29 FAIRFAX / 1ST ST	48	400	366	232	265	256	339	385	373	422	440	368	206	104	54	37	39	19	9	4362						
O 34 FAIRFAX / BEVERLY	44	392	354	232	249	252	314	362	353	409	459	377	218	98	59	44	44	20	9	4289						
O 35 FAIRFAX / OAKWOOD	52	391	351	237	271	282	315	366	352	416	467	370	220	106	57	48	51	22	9	4383						
O 34 FAIRFAX / ROSEWOOD	49	370	326	246	288	292	327	376	367	418	481	371	214	102	57	50	51	20	8	4413						
O 35 FAIRFAX / MELROSE	46	113	175	165	245	265	308	378	365	427	439	370	201	101	51	47	50	20	8	3774						
O 34 FAIRFAX / WILLOWGH	44	112	173	155	238	246	291	358	344	406	411	353	191	91	51	45	48	19	8	3584						
O 35 FAIRFAX / SANTA MO	33	90	140	148	154	174	216	292	273	322	353	299	171	97	45	50	51	19	4	2931						
O 35 FAIRFAX / FOUNTAIN	35	92	134	153	149	172	208	281	244	300	321	283	157	89	42	49	49	20	4	2782						
O 29 FAIRFAX / SUNSET	32	70	95	132	127	144	172	249	210	270	280	264	144	80	44	48	48	20	4	2433						
O 29 SUNSET / GENESEE	31	69	90	133	125	143	170	248	206	269	287	259	146	80	42	48	47	20	4	2417						
O 29 SUNSET / STANLEY	30	71	92	135	127	135	171	248	206	260	288	253	145	77	43	46	48	18	4	2397						
O 29 SUNSET / GARDNER	31	73	85	132	117	124	165	240	210	249	274	241	138	83	43	46	45	17	4	2317						
O 29 SUNSET / MARTEL	32	75	82	131	110	116	164	228	208	236	263	228	128	82	40	47	45	17	4	2236						
O 29 SUNSET / PDINSETT	33	73	77	127	118	115	171	220	193	232	260	222	129	81	38	55	46	18	4	2212						
O 30 LA BREA / SUNSET	36	65	70	122	113	106	163	211	177	222	252	218	132	86	39	54	45	17	2	2130						
O 18 LA BREA / HOLLYWOOD	36	62	68	118	116	98	156	199	172	213	242	206	127	81	36	56	42	16	1	2045						
O 18 HOLLYWOOD / SYCAMORE	36	65	67	118	116	104	155	192	165	208	225	194	122	78	38	56	45	17	1	2002						
O 18 HOLLYWOOD / ORANGE	32	62	65	112	112	107	152	176	166	197	204	179	113	75	36	54	43	17	1	1904						
O 18 HOLLYWOOD / HIGHLAND	19	33	49	84	90	94	130	147	154	185	146	146	88	65	33	55	35	16	2	1517						
O 18 HOLLYWOOD / LAS PALM	16	26	45	77	83	89	120	126	140	168	141	139	85	58	31	55	34	15	2	1450						
O 18 HOLLYWOOD / WHITLEY	15	22	42	62	67	76	111	92	116	144	129	116	68	43	27	53	31	13	2	1229						
O 18 HOLLYWOOD / WILCOX	14	21	40	54	62	66	105	84	108	131	119	98	58	38	18	44	27	13	2	1102						
O 19 HOLLYWOOD / CAHUENGA	11	20	36	44	61	66	90	80	96	123	107	85	50	40	16	41	25	13	1	1005						
O 19 HOLLYWOOD / IVAR	9	16	33	33	50	57	73	61	84	111	98	84	47	35	14	29	24	10	1	869						
O 19 HOLLYWOOD / VINE	3	14	19	17	31	39	35	33	68	87	73	67	47	25	14	24	17	9	1	623						
O 19 ARGYLE / HOLLYWOOD	4	20	17	20	31	35	32	44	69	91	83	66	47	20	16	24	15	10	0	644						
O 19 ARGYLE / YUCCA	3	20	17	19	30	28	32	44	68	81	79	64	44	15	13	21	11	9	0	598						
O 27 FRANKLIN / ARGYLE	2	16	17	16	21	22	29	34	47	64	59	47	25	11	10	17	8	6	0	451						
O 11 GOWER / FRANKLIN	2	8	13	11	10	16	21	21	27	53	38	30	10	8	6	0	0	0	0	282						
O 16 BEACHWOOD / FRANKLIN	2	11	11	12	8	9	15	12	25	49	21	24	7	4	6	3	0	0	0	219						
O 18 BEACHWOOD / MIDWAY	2	11	11	11	8	6	14	12	25	48	19	19	5	2	5	3	0	0	0	201						
O 18 BEACHWOOD / SCENIC	2	10	11	10	7	5	13	11	16	44	17	18	4	2	5	3	0	0	0	178						
O 16 BEACHWOOD / TEMPLE H	2	9	10	9	7	4	10	9	14	44	14	13	3	2	3	3	0	0	0	156						
O 18 BEACHWOOD / WINANS	1	7	10	9	7	4	5	6	13	39	13	12	1	1	3	3	0	0	0	134						
O 18 BEACHWOOD / CHEREMOY	1	7	9	8	7	3	5	4	10	34	11	7	1	1	3	3	0	0	0	112						
O 18 BEACHWOOD / GLEN ALD	1	7	7	6	6	3	4	4	8	30	10	5	1	1	2	1	0	0	0	96						
O 19 BEACHWOOD / GLEN DAK	1	7	7	6	6	3	2	4	8	26	8	4	1	1	2	1	0	0	0	87						
O 21 BEACHWOOD / WESTSHIR	0	7	6	6	2	3	2	3	0	5	5	2	1	0	0	0	0	0	0	42						
O 00 BEACHWOOD / WESTSH F																										

- 5. Prespecified number of departures:
  - \* 0 for no need and
  - \* "Given number" of departures for using the constraint.

For the equal headway timetable, an optional decision exists about the comparison between the derived and the clock headways. Finally, Figure 2 indicates that there is always a possibility of manually determining the timetable based on the headways derived by Program 1.

Frequency Setting Methods (Program 1) for SCRTD Line 217

Line 217 in Los Angeles has been selected to examine the computerized system. Line 217 is considered a heavy line that carries a relatively large number of

passengers. It is interesting to note that this line includes ADCS equipment. However, the ride-check data were collected manually and keypunched into SCRTD files. At present, the absence of reliable data from the ADCS precludes recommending its use. It is anticipated, however, that the recurring ADCS equipment problems will be resolved in the near future and that this will create opportunities for further examination of the computerized systems developed.

The geometry of Line 217 is shown in Figure 3. This line is characterized by 60 stops and 9 time points. Most of its trips are initiated at the departure terminal and terminate at the arrival terminal. Also, all of the trips cross the daily maximum load point from which the alternative timetables are to be created.

The basic input data, which are arranged by Pro-

gram 1 in a table form, are given in Table 1 for northbound Line 217. This ride-check information includes, for each hour, the observed number of buses in the third row, the minimum required frequency, and the desired occupancy in the fourth and fifth rows, respectively. The first and second columns in the tables are the distances (in kilometers) between each two adjacent stops and the stop name. The last column represents the total load across the whole day for each stop where each entry in Table 1 is a representative load for a given hour and stop. It is expected that these entries will usually be based on average values across several checks. A complete description of the input, including that for southbound Line 217, appears elsewhere (6).

The intermediate results of Program 1 are given in Table 2. The data in Table 2 indicate that the daily maximum load point for the northbound direction is the Fairfax/Rosewood stop with a total of 4,413 observed passengers during the whole day. Also, computer-generated load profiles are provided for each time period to allow the scheduler to visually observe the load variation among stops. An example is shown in Figure 4. Each asterisk in this figure represents five passengers. The area under scale is not sensitive to distances of less than 0.5 km for this visual display and, therefore, it ap-

pears that the stops are evenly spaced along the entire route. The output of Program 1 includes a measure of density for each load profile: the area under the profile curve divided by the maximum observed load times the route length. This density measure is 41.9 percent for Figure 4. Low densities mean low productivity (relatively high empty seat-kilometers) and may indicate the advisability of considering short turns.

The frequency and headway results of Program 1 are given in Table 3. The statistical (chi-square test) comparison between the results of Method 1 and Method 2 reveals that, at the 95 percent significant level, the null hypothesis about equal methods is rejected for both directions of Line 217. Consequently, for a point-check method, it is recommended that the data be gathered at the hourly maximum load points. The results of Method 4 in Table 2 are shown for three different constraint levels: 10, 20, and 30 percent of the route length (13.9 km) is allowed to have an observed load exceeding the desired occupancy. In the remaining parts of this section, Method 4 is associated with the 20 percent constraint. Bus capacity for Methods 3 and 4 is considered to be 80 passengers (see Equation 3).

The graphic comparison of the frequency results of three methods and the observed frequency is shown

TABLE 2 Maximum Load Information for Line 217 (northbound)

MAXIMUM LOAD POINT BY METHOD 1 IS FAIRFAX /ROSEWOOD --- 4413 PASSENGERS FOR DAY			
INTERMEDIATE RESULTS FOR METHOD 2			
TIME INTERVAL	MAXIMUM LOAD POINT	NO. OF PASSENGERS	
0600 0700	FAIRFAX /SAN VICE	70	
0700 0800	FAIRFAX /3RD ST	401	
0800 0900	FAIRFAX /3RD ST	370	
0900 1000	FAIRFAX /ROSEWOOD	246	
1000 1100	FAIRFAX /6TH ST FAIRFAX /DREXEL	291	
1100 1200	FAIRFAX /ROSEWOOD	292	
1200 1300	FAIRFAX /DREXEL	381	
1300 1400	FAIRFAX /1ST ST	385	
1400 1500	FAIRFAX /1ST ST	373	
1500 1600	FAIRFAX /MELROSE	427	
1600 1700	FAIRFAX /ROSEWOOD	481	
1700 1800	FAIRFAX /BEVERLY	377	
1800 1900	FAIRFAX /OAKWOOD	220	
1900 2000	FAIRFAX /OAKWOOD	106	
2000 2100	FAIRFAX /BEVERLY	59	
2100 2200	LA BREA /HOLLYWOOD HOLLYWOOD/SYCAMORE	56	
2200 2300	FAIRFAX /OAKWOOD FAIRFAX /ROSEWOOD FAIRFAX /SANTA MO	51	
2300 2400	FAIRFAX /OAKWOOD	22	
2400 2500	FAIRFAX /DREXEL FAIRFAX /3RD ST FAIRFAX /1ST ST FAIRFAX /BEVERLY FAIRFAX /OAKWOOD	9	



NUMBER OF PASSENGERS FOR INTERVAL 1600 TO 1700

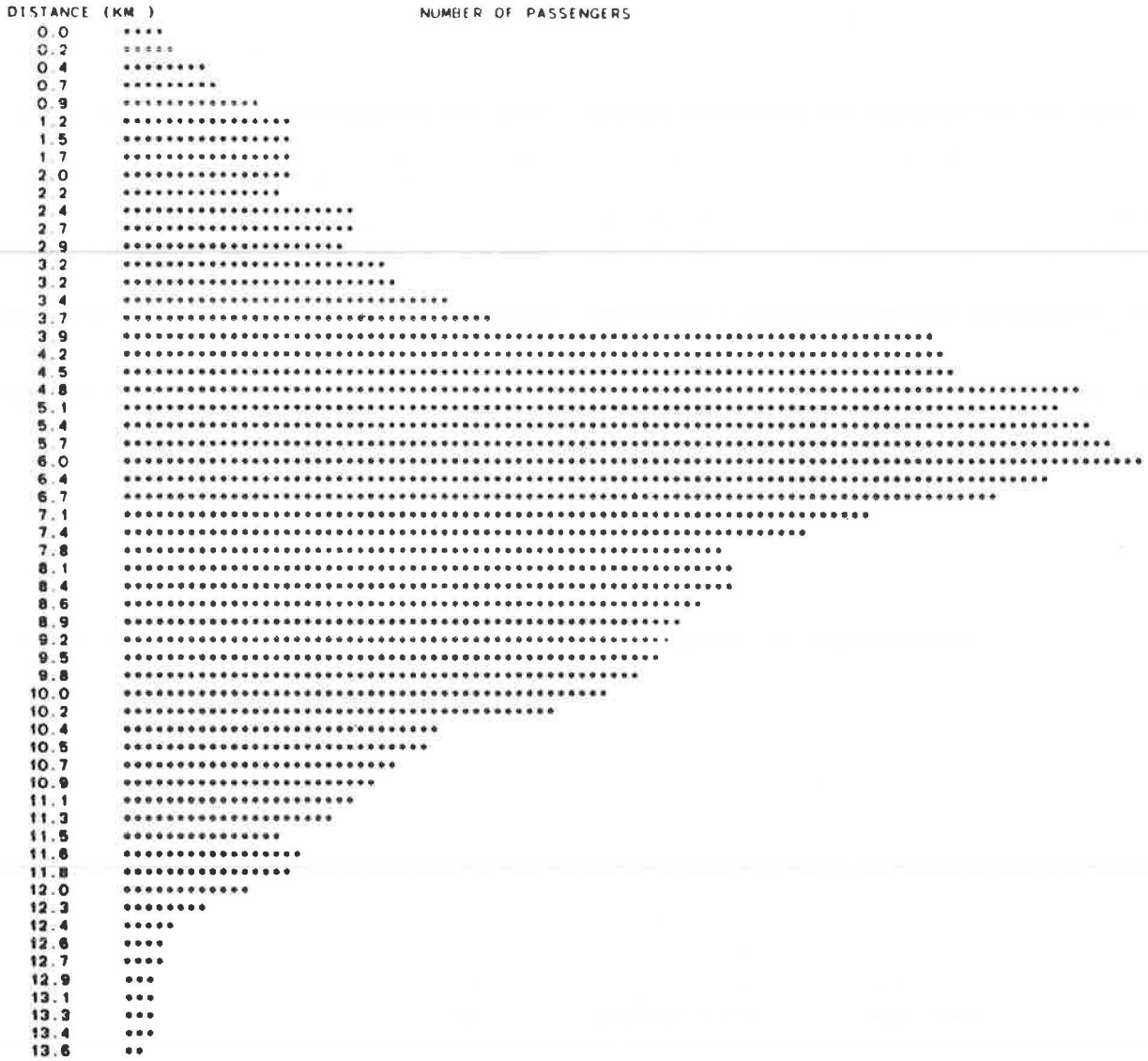


FIGURE 4 Afternoon peak load profile for Line 217 (northbound).

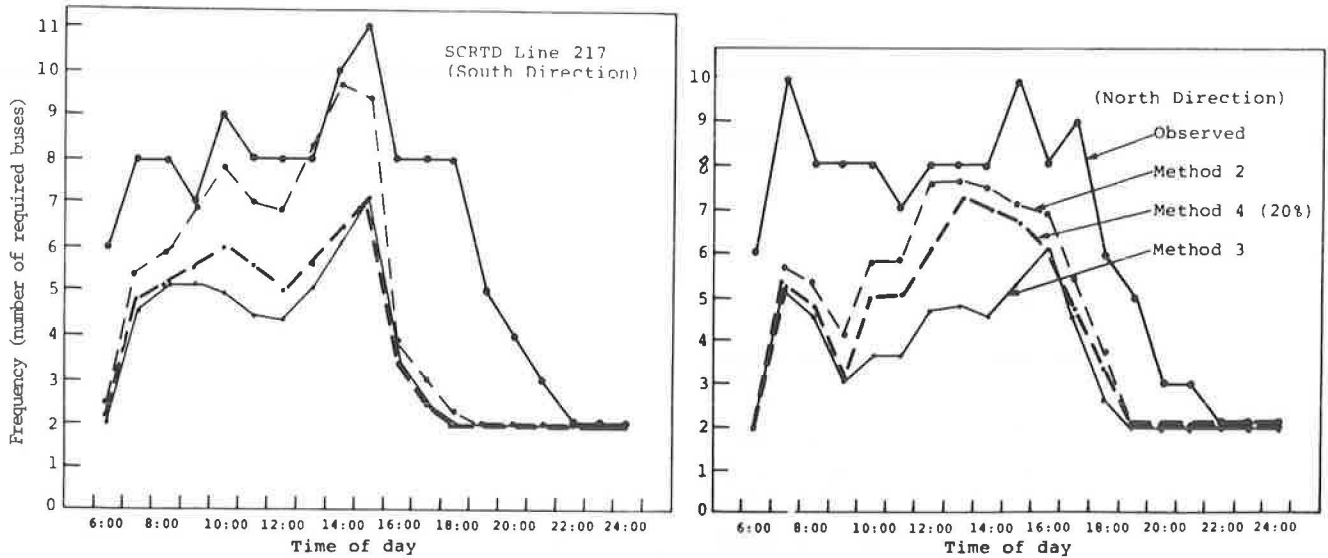


FIGURE 5 Graphic comparison of observed and derived frequencies.

TABLE 3 Frequency and Headway Results for Line 217 (northbound)

TIME INTERVAL	METHOD 1		METHOD 2		METHOD 3		METHOD 4					
							BY 10%		BY 20%		BY 30%	
	NO. OF BUSES	HEADWAY	NO. OF BUSES	HEADWAY	NO. OF BUSES	HEADWAY	NO. OF BUSES	HEADWAY	NO. OF BUSES	HEADWAY	NO. OF BUSES	HEADWAY
06:00 07:00	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.
07:00 08:00	5.28	11 MIN.	5.72	10 MIN.	5.01	12 MIN.	5.41	11 MIN.	5.11	12 MIN.	5.01	12 MIN.
08:00 09:00	4.65	13 MIN.	5.28	11 MIN.	4.62	13 MIN.	5.02	12 MIN.	4.72	13 MIN.	4.62	13 MIN.
09:00 10:00	4.09	15 MIN.	4.09	15 MIN.	3.07	20 MIN.	3.97	15 MIN.	3.07	20 MIN.	3.07	20 MIN.
10:00 11:00	5.75	10 MIN.	5.82	10 MIN.	3.63	17 MIN.	5.43	11 MIN.	4.93	12 MIN.	3.63	17 MIN.
11:00 12:00	5.83	10 MIN.	5.83	10 MIN.	3.65	16 MIN.	5.25	11 MIN.	5.05	12 MIN.	3.65	16 MIN.
12:00 13:00	6.53	9 MIN.	7.61	8 MIN.	4.76	13 MIN.	6.76	9 MIN.	6.16	10 MIN.	4.76	13 MIN.
13:00 14:00	7.51	8 MIN.	7.69	8 MIN.	4.81	12 MIN.	7.61	8 MIN.	7.21	8 MIN.	5.01	12 MIN.
14:00 15:00	7.33	8 MIN.	7.46	8 MIN.	4.66	13 MIN.	7.06	8 MIN.	6.96	9 MIN.	4.66	13 MIN.
15:00 16:00	6.96	9 MIN.	7.11	8 MIN.	5.33	11 MIN.	6.93	9 MIN.	6.73	9 MIN.	5.33	11 MIN.
16:00 17:00	6.87	9 MIN.	6.87	9 MIN.	6.01	10 MIN.	6.31	10 MIN.	6.01	10 MIN.	6.01	10 MIN.
17:00 18:00	5.30	11 MIN.	5.38	11 MIN.	4.71	13 MIN.	5.31	11 MIN.	4.91	12 MIN.	4.71	13 MIN.
18:00 19:00	3.56	17 MIN.	3.66	16 MIN.	2.75	22 MIN.	3.45	17 MIN.	3.25	18 MIN.	2.75	22 MIN.
19:00 20:00	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.
20:00 21:00	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.
21:00 22:00	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.
22:00 23:00	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.
23:00 24:00	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.
24:00 25:00	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.

TABLE 4 Computer-Generated Timetable of the First 30 Departures for Line 217 at all Time Points and at the Base or Maximum Load (Fairfax/Rosewood) Stop

THIS PROGRAM IS BASED ON THE FOLLOWING INPUT  
 .....  
 TYPE OF HEADWAYS : EQUAL (1)  
 .....  
 TYPE OF TIMETABLE: ONE METHOD (1)  
 METHOD NUMBER: 4 FROM INTERVAL: 1 TO INTERVAL: 19  
 .....  
 CLOCK HEADWAYS: NO (0)

TIMETABLE  
 .....

DEP. NUM	ADAMS WASHNGT	FAIRFAX OLYMPIC	FAIRFAX BEVERLY	FAIRFAX ROSEWOOD	FAIRFAX SANTA MO	LA BREA SUNSET	HOLLYWOOD VINE	GOWER FRANKLIN	BEACHWOOD WESTSH F
1	5.45	5.52	5.59	6.00	6.02	6.07	6.14	6.16	6.21
2	6.15	6.23	6.29	6.30	6.32	6.38	6.44	6.46	6.51
3	6.41	6.51	6.58	7.00	7.03	7.10	7.17	7.19	7.25
4	6.52	7.03	7.10	7.12	7.15	7.22	7.29	7.31	7.37
5	7.04	7.15	7.22	7.24	7.27	7.34	7.41	7.43	7.49
6	7.16	7.27	7.34	7.36	7.39	7.46	7.53	7.55	8.01
7	7.28	7.39	7.46	7.48	7.51	7.57	8.05	8.07	8.13
8	7.40	7.51	7.58	8.00	8.03	8.10	8.17	8.19	8.25
9	7.51	8.02	8.10	8.13	8.16	8.24	8.32	8.34	8.40
10	8.04	8.15	8.23	8.26	8.29	8.37	8.45	8.47	8.53
11	8.18	8.29	8.37	8.39	8.43	8.51	8.59	9.01	9.07
12	8.31	8.42	8.50	8.52	8.56	9.04	9.12	9.14	9.20
13	8.47	8.58	9.06	9.08	9.12	9.20	9.28	9.30	9.36
14	9.06	9.17	9.25	9.27	9.31	9.39	9.47	9.49	9.55
15	9.26	9.37	9.45	9.47	9.51	9.59	10.07	10.09	10.15
16	9.43	9.53	10.02	10.04	10.08	10.16	10.25	10.27	10.33
17	9.55	10.06	10.14	10.16	10.20	10.29	10.37	10.39	10.45
18	10.07	10.18	10.26	10.29	10.32	10.41	10.49	10.52	10.57
19	10.20	10.30	10.39	10.41	10.45	10.53	11.02	11.04	11.10
20	10.32	10.43	10.51	10.54	10.57	11.06	11.14	11.16	11.22
21	10.44	10.54	11.03	11.06	11.09	11.18	11.27	11.29	11.35
22	10.56	11.06	11.15	11.18	11.21	11.30	11.39	11.41	11.47
23	11.09	11.19	11.28	11.30	11.34	11.43	11.52	11.54	12.00
24	11.21	11.31	11.40	11.42	11.46	11.55	12.04	12.06	12.12
25	11.33	11.43	11.52	11.54	11.58	12.07	12.16	12.18	12.24
26	11.44	11.54	12.03	12.05	12.09	12.18	12.27	12.29	12.35
27	11.53	12.03	12.12	12.15	12.18	12.27	12.36	12.38	12.44
28	12.03	12.13	12.22	12.25	12.28	12.37	12.46	12.48	12.54
29	12.13	12.23	12.32	12.34	12.38	12.47	12.56	12.58	13.04
30	12.23	12.33	12.42	12.44	12.48	12.57	13.06	13.08	13.14

TABLE 5 Computer-Generated Timetable of the Whole Day for Line 217 at all Time Points and at the Base or Maximum Load (Fairfax/Rosewood) Stop

THIS PROGRAM IS BASED ON THE FOLLOWING INPUT  
 \*\*\*\*\*  
 TYPE OF HEADWAYS : BALANCED (2)

TYPE OF TIMETABLE: ONE METHOD (1)  
 METHOD NUMBER: 4 FROM INTERVAL: 1 TO INTERVAL: 19

CLOCK HEADWAYS: NO (0)

TIMETABLE

DEP. NUM	ADAMS WASHINGT	FAIRFAX OLYMPIC	FAIRFAX BEVERLY	FAIRFAX ROSEWOOD	FAIRFAX SANTA MO	LA BREA SUNSET	HOLLYWOOD VINE	GOWER FRANKLIN	BEACHWOOD WESTERN F
1	5.45	5.52	5.59	6.00	6.02	6.07	6.14	6.16	6.21
2	6.21	6.29	6.35	6.36	6.38	6.44	6.50	6.52	6.57
3	6.43	6.53	7.00	7.02	7.05	7.12	7.19	7.21	7.27
4	7.01	7.12	7.19	7.21	7.24	7.31	7.38	7.40	7.46
5	7.15	7.26	7.33	7.35	7.38	7.45	7.52	7.54	8.00
6	7.24	7.34	7.42	7.43	7.46	7.53	8.00	8.02	8.08
7	7.32	7.43	7.50	7.52	7.55	8.01	8.09	8.11	8.17
8	7.40	7.51	7.58	8.00	8.03	8.10	8.17	8.19	8.25
9	7.46	7.57	8.05	8.07	8.11	8.19	8.27	8.29	8.35
10	7.56	8.07	8.15	8.17	8.21	8.29	8.37	8.39	8.45
11	8.12	8.23	8.31	8.34	8.37	8.45	8.53	8.55	9.01
12	8.23	8.34	8.42	8.45	8.48	8.56	9.04	9.06	9.12
13	8.43	8.54	9.02	9.04	9.08	9.16	9.24	9.26	9.32
14	8.59	9.10	9.18	9.21	9.24	9.32	9.40	9.42	9.48
15	9.17	9.28	9.36	9.39	9.42	9.50	9.58	10.00	10.06
16	9.42	9.53	10.01	10.03	10.07	10.16	10.24	10.26	10.32
17	9.56	10.07	10.15	10.18	10.21	10.30	10.38	10.41	10.46
18	10.10	10.21	10.29	10.31	10.35	10.44	10.52	10.54	11.00
19	10.20	10.31	10.39	10.42	10.45	10.54	11.02	11.04	11.10
20	10.33	10.43	10.52	10.54	10.58	11.06	11.15	11.17	11.23
21	10.45	10.55	11.04	11.06	11.10	11.19	11.28	11.30	11.36
22	10.54	11.04	11.13	11.16	11.19	11.28	11.37	11.39	11.45
23	11.09	11.19	11.28	11.30	11.34	11.43	11.52	11.54	12.00
24	11.18	11.28	11.37	11.39	11.43	11.52	12.01	12.03	12.09
25	11.32	11.42	11.51	11.53	11.57	12.06	12.15	12.17	12.23
26	11.43	11.53	12.02	12.04	12.08	12.17	12.26	12.28	12.34
27	11.51	12.01	12.10	12.12	12.16	12.25	12.34	12.36	12.42
28	12.02	12.12	12.21	12.24	12.27	12.36	12.45	12.47	12.53
29	12.12	12.22	12.31	12.34	12.37	12.46	12.55	12.57	13.03
30	12.19	12.29	12.38	12.40	12.44	12.53	13.02	13.04	13.10
31	12.29	12.39	12.48	12.50	12.54	13.03	13.12	13.14	13.20
32	12.41	12.51	13.00	13.02	13.06	13.15	13.24	13.26	13.32
33	12.45	12.55	13.04	13.07	13.10	13.19	13.28	13.30	13.36
34	12.53	13.03	13.12	13.15	13.18	13.27	13.36	13.38	13.44
35	13.03	13.13	13.22	13.24	13.28	13.37	13.46	13.48	13.54
36	13.12	13.22	13.31	13.33	13.37	13.46	13.55	13.57	14.03
37	13.24	13.34	13.43	13.46	13.49	13.58	14.07	14.09	14.15
38	13.32	13.42	13.51	13.54	13.57	14.06	14.15	14.17	14.23
39	13.39	13.50	13.59	14.02	14.06	14.15	14.25	14.28	14.33
40	13.45	13.56	14.05	14.08	14.12	14.21	14.31	14.33	14.39
41	13.53	14.04	14.13	14.16	14.20	14.29	14.39	14.42	14.47
42	14.07	14.17	14.27	14.29	14.33	14.42	14.52	14.55	15.01
43	14.14	14.24	14.34	14.36	14.40	14.49	14.59	15.02	15.08
44	14.25	14.35	14.45	14.47	14.51	15.00	15.10	15.13	15.19
45	14.32	14.43	14.52	14.55	14.59	15.08	15.18	15.21	15.27
46	14.41	14.52	15.01	15.04	15.08	15.17	15.27	15.30	15.36
47	14.53	15.04	15.13	15.15	15.20	15.29	15.39	15.42	15.48
48	14.57	15.08	15.17	15.20	15.24	15.33	15.43	15.46	15.52
49	15.08	15.19	15.28	15.31	15.35	15.44	15.54	15.57	16.03
50	15.14	15.25	15.34	15.37	15.41	15.50	16.00	16.03	16.09
51	15.24	15.35	15.44	15.46	15.51	16.00	16.10	16.13	16.19
52	15.36	15.47	15.56	15.58	16.03	16.12	16.22	16.25	16.31
53	15.45	15.56	16.05	16.08	16.12	16.21	16.31	16.34	16.40
54	15.58	16.09	16.18	16.21	16.25	16.34	16.44	16.47	16.53
55	16.08	16.19	16.28	16.31	16.35	16.44	16.54	16.57	17.03
56	16.20	16.31	16.40	16.42	16.47	16.56	17.06	17.09	17.15
57	16.26	16.37	16.46	16.49	16.53	17.02	17.12	17.15	17.21
58	16.37	16.48	16.57	17.00	17.04	17.13	17.23	17.26	17.32
59	16.47	16.58	17.08	17.10	17.14	17.23	17.33	17.37	17.42
60	16.58	17.09	17.18	17.21	17.25	17.34	17.44	17.47	17.53
61	17.10	17.21	17.30	17.33	17.37	17.46	17.56	17.59	18.05
62	17.29	17.40	17.49	17.52	17.56	18.05	18.15	18.18	18.24
63	17.41	17.52	18.00	18.03	18.07	18.15	18.26	18.28	18.35
64	17.56	18.07	18.15	18.18	18.22	18.31	18.41	18.43	18.50
65	18.15	18.26	18.34	18.37	18.41	18.49	19.00	19.02	19.09
66	18.35	18.46	18.54	18.56	19.01	19.09	19.20	19.21	19.29
67	19.09	19.18	19.26	19.28	19.30	19.38	19.47	19.49	19.55
68	19.39	19.48	19.55	19.57	20.00	20.08	20.17	20.19	20.25
69	20.04	20.12	20.19	20.21	20.23	20.31	20.39	20.41	20.47
70	20.41	20.49	20.56	20.58	21.00	21.08	21.16	21.18	21.24
71	21.10	21.18	21.25	21.27	21.29	21.37	21.45	21.47	21.53
72	21.42	21.50	21.57	21.58	22.01	22.09	22.17	22.19	22.25
73	22.11	22.19	22.26	22.27	22.30	22.37	22.46	22.48	22.54
74	22.42	22.50	22.57	22.59	23.01	23.09	23.17	23.19	23.25
75	23.00	23.08	23.15	23.16	23.19	23.27	23.35	23.37	23.43
76	23.43	23.51	23.58	23.59	24.02	24.10	24.18	24.20	24.26
77	0.55	0.03	0.10	0.12	0.14	0.22	0.30	0.32	0.38
78	0.43	0.51	0.58	1.00	1.02	1.10	1.18	1.20	1.25

in Figure 5 for both directions of Line 217. It can be easily seen that the provided frequencies in both directions represent an excessive number of bus runs. The desired occupancy for each time period appears in Table 1 in the fourth row and was set forth by SCRTD schedulers. The use of these load factors and either Method 2 or Method 4 can result in significant resource savings. It is interesting to note that Method 4 results in much lower frequency than Method 2, particularly in the southbound direction. The absolute minimum frequency to accommodate the passenger load while neglecting the load factors is presented by Method 3, and in most hours is half the presently provided frequency.

#### Alternative Timetables (Program 2) for SCRTD Line 217

The PL/1 Program 2, which is based on the procedures described in Ceder (6), is used for the SCRTD Line 217 to construct alternative timetables.

Eighteen different combinations of runs have been selected for each direction of travel. Tables 4 and 5 are computer-generated timetables for the northbound direction. Table 4 (for equal headway) gives only the first 30 departures, and Table 5 presents the whole day's timetable. Nonetheless, it is possible to examine the differences between the equal and the balanced headway timetables.

Several observations can be made on the basis of results presented elsewhere (6). The results of Method 4 indicate significant resource saving in comparison with the results of Method 2, particularly in the southbound direction. This can also be seen in Figure 5. The combinations of methods used indicate that the use of Method 4 during peak periods only does not result in significant saving in comparison with Method 2 results. Consequently, Method 4 may be particularly useful during off-peak hours. For the southbound direction, the clock headway timetable using Method 2 results in the same number of departures and fleet size measure as Method 2 without clock headway. This may provide an opportunity to introduce the clock headway timetable at the main (daily maximum load) Fairfax/Beverly stop. It is worth mentioning that the clock headway pattern is not maintained along the entire route because of different running times between time points.

Certainly, the large number and variety of timetables may complicate the decision-making process for schedulers. However, it provides an opportunity

to examine rapidly different timetable and frequency scenarios. It is anticipated, however, that the skilled scheduler, while recognizing the full potential of the procedures, will select only a few alternatives to compare.

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#### REFERENCES

1. P.G. Furth and N.H.M. Wilson. Setting Frequencies on Bus Routes: Theory and Practice. *In* Transportation Research Record 818, TRB, National Research Council, Washington, D.C., 1981, pp. 1-7.
2. H.N. Koutsopoulos, A. Odoni, and N.H.M. Wilson. Determination of Headways as a Function of Time Varying Characteristics on a Transit Network. Proc., 3rd International Workshop on Transit Vehicle and Crew Scheduling, University of Montreal, Transportation Research Centre, June 1983.
3. M. Lampkin and P.D. Saalmans. The Design of Routes, Service Frequencies and Schedules for a Municipal Bus Undertaking: A Case Study. *Operation Research Quarterly*, Vol. 18, No. 4, 1967, pp. 375-397.
4. A. Ceder. Practical Methodology for Determining Dynamic Changes in Bus Travel Times. *In* Transportation Research Record 798, TRB, National Research Council, Washington, D.C., 1981, pp. 18-22.
5. A. Ceder. Bus Frequency Determination Using Passenger Count Data. *Transportation Research*, Part A, forthcoming.
6. A. Ceder. Methods for Setting Bus Timetables. Multisystems, Inc., Cambridge, Mass.; Transportation Systems Center Project Evaluation Series, Service and Management Demonstration Program, UMTA, U.S. Department of Transportation, Feb. 1984.

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