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**UMTA/TSC Project Evaluation Series**

# **Methods for Setting Bus Timetables**

## **Service and Management Demonstration Program**

**Draft Interim Report**

**September 1983**

**Prepared for:**



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## ***Executive Summary***

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This document presents one component of an extensive program to develop applications for bus Automatic Data Collection systems (ADCS). The overall description of the program is displayed in a flowchart in Figure 1 of the first chapter. This study, basically, provides alternative methods for constructing bus timetables using passenger load data. The procedures developed are accompanied by a step-by-step explanation using the same scheduling example throughout the entire report. This description is intended both to serve as a guideline for adequately using the methods (even for a novice scheduler) and to allow for a scheduler's response in order to refine and adjust the procedures as part of future endeavors.

Current practices in bus properties show that sufficient data for service operations planning seldom exist. Manual data collection efforts are costly and, consequently, must be used sparingly. As a result, detailed information on passenger demand and service characteristics is generally not available at the route level. Without this information the efficient deployment of bus service commensurate with demand is impossible. Thus, a major reason for bus properties to be interested in the use of ADCS is the hope of gaining badly needed data at greatly reduced unit cost. In order to assist the bus industry in implementing these systems, the office of Service and Management Demonstrations, Urban Mass Transit Administration (UMTA) sponsored a major demonstration of ADCS applications in cooperation with the Southern California Rapid Transit District

(SCRTD). It is expected that the resulting information will improve the utilization of buses and drivers through the design of more efficient schedules.

In order to accomplish this objective, a general program was established to develop applications for ADCS. The program as a whole intends to serve both routes with ADCS and without ADCS. Its major objectives are to:

1. improve management and operations by developing, improving, validating and testing models and procedures for bus operations planning;
2. improve levels of service through increased reliability resulting from better control and response;
3. improve productivity and efficiency by better matching supply and demand;
4. reduce data gathering, processing, and reporting costs; and
5. develop vital components of a management information system pertaining to operations and passenger behavior.

This study is related directly to the first and third objectives.

A cost-effective and efficient bus timetable embodies a compromise between passenger comfort and cost of service. A good match between bus supply and passenger demand occurs when bus schedules are constructed so that the observed passenger demand is accommodated while the number of vehicles used is minimized. This will minimize the operator cost in terms of driver's wages and capital costs required to purchase buses. These important issues reflect part of the overall ADCS applications project objectives and are directly related to the following objectives of this study:

1. to evaluate alternative timetables in terms of required resource (number of bus runs and fleet size required).

2. to improve the correspondence of bus departure times with passenger demand while minimizing resources.
3. to provide alternative timetables (along with bus utilization measures) for the schedulers use in specific scheduling situations.
4. to permit, in the timetable construction procedure, direct bus frequency changes for possible exceptions (known to the scheduler) which do not rely on passenger demand data.
5. to allow the construction of timetables with headway smoothing techniques (similar to that performed manually) in the transition segments between adjacent time periods.
6. to integrate different headway setting and different timetable construction methods.

This report attempts to fulfill these objectives and is organized as follows. Chapter 2 describes the background of the study and reviews current timetable construction procedures including a brief review of four methods for setting bus headways (Ref. 4). The output of these methods serves as part of the input to the program developed in this work. Chapter 3 presents alternative timetable options and bus utilization measures for comparing timetables. In addition, it discusses and interprets the procedure to construct the initial timetable at one point and then to extend it using the running time information, to all the other timepoints. These alternative timetables constitute the framework of the computer program and are considered in the remainder of this report. Chapter 4 presents smoothing procedures for bus departure times for the case of evenly spaced headways. Chapter 5 describes procedures to balance passenger loads by allowing the headways to be unevenly spaced. Chapter 6 describes the elements of the mainframe computer program needed to establish alternative timetables and compares several test runs on real data from SCRTD (line 217 in Los Angeles). Finally, Chapter 7 summarizes the report and discusses possible future applications of the ADCS project.

The final product of this work, described in Chapter 6, consists of a set of computer programs that perform:

- (i) conversion from the bus property (SCRTD) main-frame files to an adequate input file,
- (ii) analysis of four methods for setting bus frequencies,
- (iii) creation of alternative timetables at a single timepoint, and
- (iv) creation of a public timetable at all the route timepoints (this program is still in preparation).

It is planned to initially test this product at SCRTD in Los Angeles. The new and computerized techniques to derive bus frequencies and construct alternative timetables will be evaluated at two levels: (1) their appropriateness for routes with non-ADCS equipped buses in which the data is gathered manually, (2) their appropriateness for routes with ADCS in which the data is automatically generated. Undoubtedly, with the anticipated reliable and vast amount of passenger load data from the ADCS it will be possible to systematically investigate the variations of passenger demand. However, it is not likely that in the near future all the routes will be operated by ADCS equipped buses. On the other hand the computer scheduling files will probably be based on one system rather than on two systems which distinguish routes with and without ADCS. Therefore, careful attention must also be given to routes without ADCS.

The outcome of this work can be generally described in light of the six study objectives. The procedures developed provide alternative timetables in terms of bus departure times at one timepoint. Each timetable is accompanied by two comparison measures which are used as an evaluation indicator in conjunction with resource saving. The first measure is the total required bus runs (departures) and the second is the minimum required fleet size at the route level. These

evaluation measures fulfill the first objective. One set of options in selecting the procedure to construct the timetables is referred to as balancing passenger loads on individual buses while allowing unevenly spaced headways. The underlying approach in this set of options is to shift departure times of individual buses so that to obtain even average loads instead of even headways. In addition, this procedure ensures that while shifting the departure times the number of bus runs and the minimum fleet size at the route level are maintained. This balancing the loads approach fulfills the second objective.

The third objective of the study is to provide flexible and alternative timetables to be used in a practical scheduling environment. This objective is fulfilled by permitting the scheduler to request different timetables from a variety of possible combinations. By simply keypunching approximately 5 digits the scheduler can request equal or balanced (uneven) headways, combinations of frequency setting methods, clock or the derived headways and also to prespecify the number of departures. Part of the input to the timetable construction program is based on different sets of frequencies (usually non-integer derived values). The scheduler can either interject his own set of intuitive-or experience-based frequencies, or can substitute some of the derived frequencies. In this manner possible scheduling exceptions (e.g., special passenger demand due to a sport event) could be accomplished to fulfill the fourth study's objective.

The common manual process to create timetables is often encountered by a problem in smoothing the headways in the transition segments between adjacent time periods. The procedure to simply average the transitional headways does not guarantee that the average observed loads will not exceed the desired bus occupancy. The procedure developed for both the equal and balanced headways ensure, in an average sense, the fulfillment of the desired occupancy constraint -- the necessity expressed in the fifth objective of this study. The sixth and last objective is fulfilled by allowing the user

(scheduler) to request the selection of different frequency setting methods for different time periods. In this way the scheduler can select for peak periods methods which are more sensitive to resource saving (e.g., see Method 4 in Chapter 3) and for off-peak periods methods which are more sensitive to passenger comfort (e.g., see Method 2 in Chapter 3).

This study is one element of a set of procedures that will attempt to demonstrate the possible benefits that can occur to both operators and passengers when using new and improved methods for bus operations planning. The procedures to be developed are outlined in the last chapter of this work and will be especially based on ADCS. Undoubtedly, as these future research tasks take place more knowledge will be gained and further use of the new ADCS technology will emerge.

## **Chapter 1: Introduction and Objectives**

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It is well-known that making more productive use of existing resources is an important endeavor of any transit system. The transit planning process includes four basic components; performed in sequence: (1) network route design, (2) setting timetables, (3) scheduling vehicles to trips, and (4) assignment of drivers. It is desirable for all components to be planned simultaneously to exploit the system's capability to the greatest extent and to maximize the system's productivity and efficiency. However, this planning process is extremely cumbersome and complex and therefore seems to require separate treatment of each component, with the outcome of one fed as an input to the next component.

In most bus properties world-wide the bulk of resources is devoted to the last two planning components: vehicle blocking (the arrangement of a string of trips for individual buses) and driver run-cutting (the splitting and recombination of vehicle blocks into legal driver shifts or runs). These two time consuming and complex components challenge researchers to develop automated procedures which will provide more efficient, controllable and responsive schedules. The accumulated knowledge about these automated computerized procedures is summarized in the professional papers presented in the second (Leeds, England, 1980) and third (Montreal, Canada, 1983) International Workshops on Vehicle and Crew Scheduling (Refs. 1, 2). However, the initial two components of the planning process: network route design and setting timetables have not received

similar research attention and hence deserve particular consideration (Ref. 3).

This report concentrates on one of the two "neglected" components and attempts to establish automated procedures for efficiently setting timetables. This study is a continuation of previous research concerning the appraisal of methods for bus frequency determination (Ref. 4). The research is performed within the context of demonstrating applications of Automated Data Collection System (ADCS) for enhancing bus service productivity and efficiency. The remainder of this chapter briefly describes the overall program to develop applications for ADCS, and also emphasizes the study's objectives and organization.

#### 1.1 The overall program to develop applications for ADCS

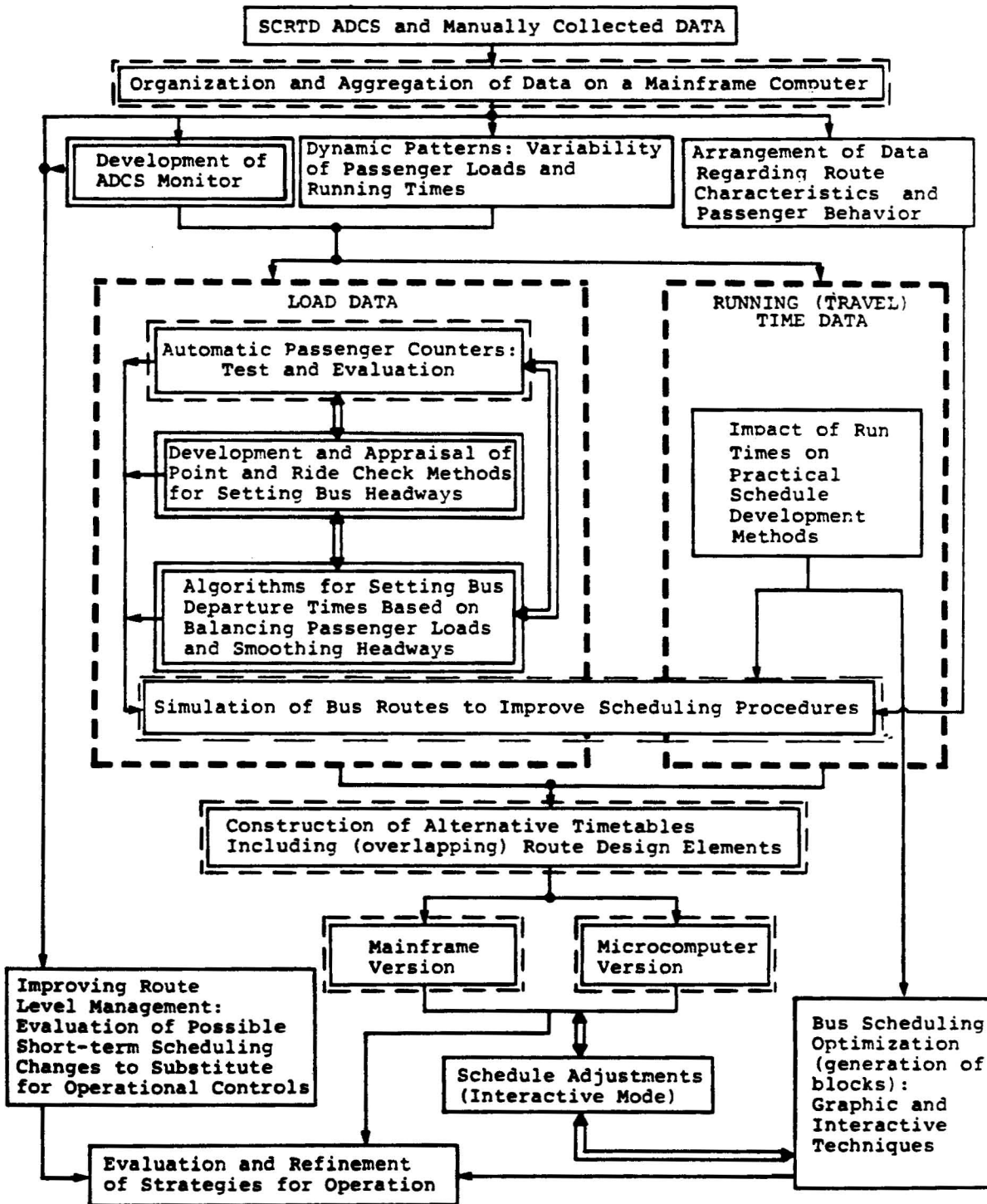
Current practices in bus properties show that sufficient data for service operations planning seldom exist. Manual data collection efforts are costly and, consequently, must be used sparingly. As a result, detailed information on passenger demand and service characteristics is generally not available at the route level. Without this information the efficient deployment of bus service commensurate with demand is impossible. Thus, a major reason for bus properties to be interested in the use of ADCS is the hope of gaining badly needed data at greatly reduced unit cost. In order to assist the bus industry in implementing these systems, the office of Service and Management Demonstrations, Urban Mass Transit Administration (UMTA) sponsored a major demonstration of ADCS applications in cooperation with the Southern California Rapid Transit District (SCRTD). It is expected that the resulting information will improve the utilization of buses and drivers through the design of more efficient schedules.

In order to accomplish this objective, a general program was established to develop applications for ADCS as shown in flowchart form in Figure 1. The program as a whole intends to serve both routes with ADCS and without ADCS. Its major objectives are to:



Figure 1

GENERAL DESCRIPTION OF PROGRAM TO DEVELOP APPLICATIONS FOR ADCS



Key: Flow of Information →

Under Study  

Interactions Between Components ⇔

Study Completed

1. improve management and operations by developing, improving, validating and testing models and procedures for bus operations planning;
2. improve levels of service through increased reliability resulting from better control and response;
3. improve productivity and efficiency by better matching supply and demand;
4. reduce data gathering, processing, and reporting costs; and
5. develop vital components of a management information system pertaining to operations and passenger behavior.

Figure 1 indicates the components which have been completed, those presently under study and those which have not yet been started. Three projects have been completed: (i) development and appraisal of point and ride check methods for setting bus headways--reported in Ref. 4., (ii) development of an ADCS monitor--reported in draft form (Ref. 5) and, (iii) algorithms for setting bus departure times based on balancing loads and smoothing headways--the study reported here.

This study, as shown in Figure 1, relates to work discussed in a previous report (Ref. 4) and to a study about testing and evaluating Automatic Passenger Counters (APCs) at SCRTD. These automatic counters presently depend on treadle mats encasing electrical switch plates to sense boardings and alightings. Each ADCS equipped bus contains two treadle mats in each doorway, a passenger counter logic module, a microprocessor, and a mobile radio. A comprehensive and recent assessment study about APC's is reported in Ref. 6. Nevertheless, there are still serious and recurring accuracy problems with the APC's installed on 200 buses at SCRTD and a study is being performed to analyze the extent of the problems. It is obvious, that the ridership data collected by the APC's are vital to all demonstration application, and therefore special attention must be given to the issue's of accuracy and reliability.

The flowchart in Figure 1 includes three more components which are directly related to this study. That is the tasks related to timetable construction with route design elements including its mainframe and microcomputer versions. The techniques described here are part of the input to the schedule construction process both at the microcomputer and mainframe levels. The remaining parts of Figure 1 include the major tasks which need to be performed for achieving the overall program goals.

## 1.2 Study objectives and outline

A cost-effective and efficient bus timetable embodies a compromise between passenger comfort and cost of service. A good match between bus supply and passenger demand occurs when bus schedules are constructed so that the observed passenger demand is accommodated while the number of vehicles used is minimized. This will minimize the operator cost in terms of driver's wages and capital costs required to purchase buses. These important issues reflect part of the overall ADCS applications project objectives and are directly related to the following objectives of this study:

1. to evaluate alternative timetables in terms of required resource (number of bus runs and fleet size required).
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3. to provide alternative timetables (along with bus utilization measures) for the schedulers use in specific scheduling situations.
4. to permit, in the timetable construction procedure, direct bus frequency changes for possible exceptions (known to the scheduler) which do not rely on passenger demand data.
5. to allow the construction of timetables with headway smoothing techniques (similar to that performed manually) in the transition segments between adjacent time periods.

6. to integrate different headway setting and different timetable construction methods.

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## **Chapter 2: Background and Initial Procedures**

---

The "setting timetables" component of the bus planning process is one critical determinant of system effectiveness since its purpose is, in part, to deal with variations in passenger demand. The construction of timetables is performed on the basis of passenger counts, and must comply with service frequency constraints. This chapter presents an overview of current practices for establishing timetables, and describes the background and initial work of this study.

### 2.1 Methods and practice for timetable preparation

Passenger demand at the route-level is generally gathered 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). While the 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 world-wide are commonly based on the following service standards: (i) adequate space will be provided to meet passenger demand, and (ii) 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 in

obtained by dividing the maximum observed passenger flow by a load standard (desired occupancy, e.g., number of seats). The second requirement is met by establishing policy headways (maximum allowed headway) which usually are 30 or 60 minutes.

Several researchers have approached the bus headway determination problem through mathematical programming techniques (Refs. 7, 8, 9). However; these mathematical programming models have not been generally adopted by transit schedulers since they are not sensitive to a great variety of system specific operational constraints. For example, they can not simultaneously determine even spaced headways and uneven spaced headways for situations of scheduling exceptions.

In current practice schedule changes are performed using a mix of manual and computer generated reports. The use of computerized reports has been established in many large bus properties (e.g. SCRTD-Los Angeles, TTC-Toronto, EGGED-Israel). The procedure employed by SCRTD to develop timetables will be used as an example. Based on 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. the 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., the 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 (usually this is the time point at which the maximum passengers flow is observed; a time point is generally a bus stop at a major intersection or facility which appears on the public timetable)
4. initial departure (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. the 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. following the updating of the schedule, the changes (or the new timetable) are marked on the timetable print instruction sheet which is transferred to marketing.

The scheduling data files of SCRTD include about 40,000 trips. The data is collected manually by checkers and then keypunched. The computerized reports are furnished by IBM 1401 and UNIVAC 1106 computers. All of the timetable and run cutting tasks are performed manually with work sheets or computer listings prepared for key entry and computer processing. About 40% of the scheduler's time is devoted to data entry and proofreading computer generated reports.

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

1. elimination of manual steps
2. improved accuracy
3. 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 decision will be made based on 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 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 base for the scheduler's decision. For example, the ADCS may 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 (e.g. for a statistical analysis of bus running time data see Ref. 10).

## 2.2 Methods for Setting Bus Headways

This section presents and clarifies earlier work (see Ref. 4) which is strongly related to the procedures described in the following chapters. This early work describes four alternative bus frequency determination methods to fulfill two major objectives:

1. the setting of bus frequencies to both maintain adequate service quality and minimize the number of buses in the schedule.
2. the efficient allocation of the resources to gather passenger load data.

The first objective is to evaluate alternative methods to construct 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 having ADCS this question is also relevant since only part of the overall fleet will be equipped with ADCS. The ADCS may be rotated among several groups of routes, depending on whether it is worthwhile to gather point check as opposed to ride check data.

The four frequency determination methods in Ref. 4 can be summarized in the following four equations:



(a) Two point check methods for time period j

$$\text{Method 1: } (\text{Frequency})_j = \frac{\left( \frac{\text{Load at the daily}}{\text{max load point}} \right)_j}{(\text{Desired Occupancy})_j} \quad (1)$$

$$\text{Method 2: } (\text{Frequency})_j = \frac{\left( \frac{\text{Load at the hourly*}}{\text{max. load point}} \right)_j}{(\text{Desired Occupancy})_j} \quad (2)$$

(b) Two ride check methods for time period j

$$\text{Method 3: } (\text{Frequency})_j = \text{MAX} \left[ \frac{\left( \frac{\text{Area under the}}{\text{load profile in}} \right)_j}{\left( \frac{\text{Desired}}{\text{Occupancy}} \right)_j \times \left( \frac{\text{Route}}{\text{length}} \right)}, \frac{\left( \frac{\text{Load at the}}{\text{hourly* max}} \right)_j}{\text{Bus Capacity}} \right] \quad (3)$$

Method 4:

(Frequency)<sub>j</sub> = same as Method 3, but

subject to a constraint that limits the length of the route over which the load may exceed the product:

$$(\text{Frequency})_j \times (\text{Desired occupancy})_j \quad (4)$$

The first method is based on data gathered at one point during the whole 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

---

\* Hourly or other time period (it may coincide with j)

\*\* or passenger-miles

maximum load observed in each time period (usually an hour) rather than the whole day. Certainly, it is less costly and more convenient to station an observer (when the data is collected manually) at one point during the entire working day, than to assign observers to different point at every time period. When ride check data is available (either collected manually or by ADCS) the program established in Reference 4 compares Methods 1 and 2, and as the result the scheduler can decide about the appropriate point check procedure. An example is given in the next section to clarify these methods.

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 max load in each period  $j$  in Method 2. Method 3 also guarantees, in an average sense, that passengers the on-board on the max load segment will not experience crowding above the given bus capacity (number of seats + max allowable standees). This method is useful for situations in which the scheduler wishes to know the number of bus runs he can save by raising the desired occupancy standard, without incurring overcrowding. However, Method 3 can result in unpleasant travel for an extended distance in 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 having loads greater than the desired occupancy. This is in essence Method 4. The example presented in the next section demonstrates the two ride check methods as well as the two point check methods.

A PL/1 program has been written for all the 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 (for details - see Reference 4). 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% of the route length is allowed to have an observed load exceeding the desired one (these criteria can obviously be varied). The description of the program input appears in Appendix A.

### 2.3 Example of a 3-Hour Scheduling Task

A simple example will be presented to demonstrate and clarify the various methods and algorithms employed. This example is used throughout the entire report.

The basic required input for the frequency determination program is indicated in Table 1. It consists of (1) distances (in kilometers) between stops, (2) desired occupancy per bus, (3) policy (maximum) headway for each time interval, (4) the number of scheduled and observed buses in each time interval, (5) the observed load (an average value or with a consideration of its variability) between each two adjacent stops and for each time interval, (6) round trip time (including layover and turn around times) in each time interval, and (7) bus capacity (for one bus type). A 3-hour operation period (06:00 - 09:00) is chosen for simplicity in this example. An important assumption is that the observed loads in each hour are based on a uniform passenger arrival rate (demand). That is, the number of passengers carried on the first bus in each hour is divided proportionally to reflect the demand in two intervals: (1) the start of the time period and the departure time of the first bus in that period, (2) last departure time in the previous period and the start of the considered period. The last column in Table 1, the total number of passengers observed on-board at each stop, reveals that stop 3 is the daily max. load point. Using equation (1) and dividing the three hourly observed loads: 116, 387, 273 by the desired occupancy: 50, 65, 65,

Table 1

BASIC INPUT DATA FOR THE EXAMPLE PROBLEM REGARDING DETERMINATION OF BUS FREQUENCY FOR EACH TIME PERIOD

Distance (km) between stops	Stop Name	Loads in each time period			Total Load
		06:00-06:59	07:00-07:59	08:00-09:00	
0	departure terminal	77	261	118	456
3	stop 1	132	323	294	749
2	stop 2	119	411	231	761
2	stop 3	116	387	273	776
3	arrival terminal	--	--	--	--
Number of observed scheduled buses		2	6	4	
Desired occupancy (load factor or load standard)		50	65	65	
Policy headway (minutes)		30	30	30	
Single mean round trip time, including layover and turn around times (minutes)		55	67	55	
Bus capacity (number of seats + max allowable standees)		80			
Area under the load profile (passenger-kilometers)		1081	3412	2223	

respectively, gives the frequencies. Then, the associated integer headways (in minutes) are obtained by simply dividing the length of the time interval by the frequency, and rounding it to the nearest integer. These results appear in Table 2. The hourly max load points are stops 1, 2 and 7 for the three time periods, respectively. Using equation (2), the frequencies and their associated headways are derived and they appear in Table 2.

The last row in Table 1 provides the productivity measure passenger-kilometers for each time interval. Dividing this measure, according to equation (3), by the route length (10 kilometers) and desired occupancy results in the Method 3 frequencies only the first two time intervals as shown in Table 2. The frequency of the third time interval according to equation (3) is determined by the bus capacity constraint:  $\max(2223/65 \times 10, 294/80) = 3.67$ . The load profiles associated with the three time periods are shown in Figure 2. In this figure, the average load level (area under the load profile divided by the route length) is also indicated. A straight line is drawn across the load profile at each average load level. The area above this line, overlapped by the load profile, represents passenger-kilometers in which the load exceeds the desired occupancy. Method 4 establishes a level of service consideration by restricting the total route distance having loads greater than the desired occupancy, as expressed in equation (4). For example, in the second time period (07:00-07:59), Method 3 requires 5.25 buses (11 minutes headway) as opposed to 6.32 buses (9 minutes headway) for Method 2. However, when Method 3 is applied (to save bus runs) the load from Stop 2 to the arrival terminal will be, in an average sense, greater than the desired load (see Figure 2): That is, five kilometers (50% of route length) will experience overcrowding. If we select an overcrowding limit of only 20% of the route length for Method 4 one should increase the 341.2 load level in Figure 2 to the level at which only 20% or less of the route length having overlapped areas between the load

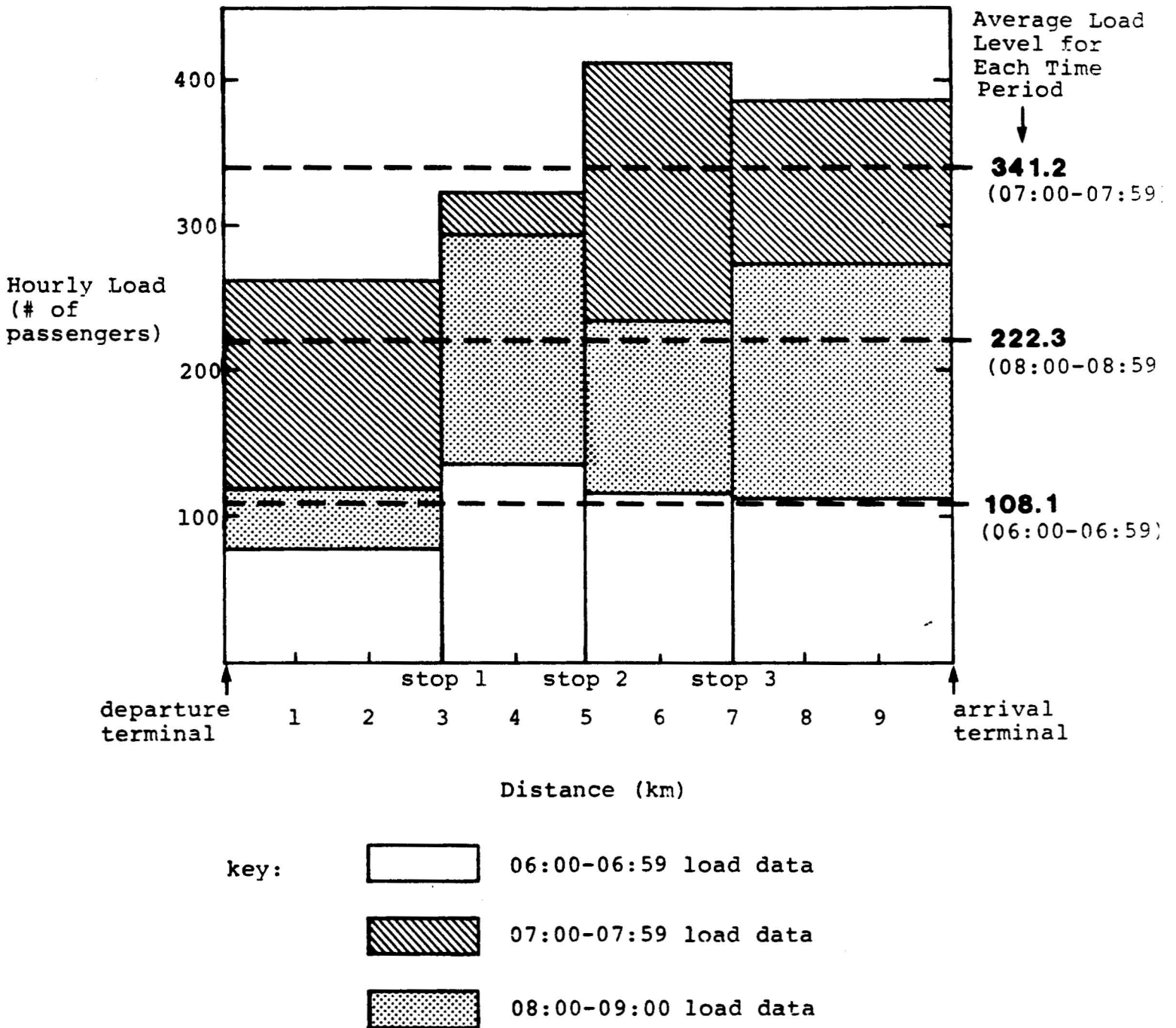
Table 2

FREQUENCY AND HEADWAY RESULTS OF THE EXAMPLE PROBLEM

Time Interval	Method 1		Method 2		Method 3		Method 4 (20%)	
	Freq	Headway	Freq	Headway	Freq	Headway	Freq	Headway
06:00-06:59	2.32	26	2.64	23	2.16	28	2.38	25
07:00-07:59	5.95	10	6.32	9	5.25	11	5.95	10
08:00-08:59	4.20	14	4.52	13	3.67	16	4.20	14

Figure 2

GRAPHIC REPRESENTATION OF THE EXAMPLE LOAD PROFILES WITH THE DETERMINANT LOAD VALUE FOR METHODS 3 AND 4



profile and that above the required load level. In this case the load level between stop 3 and the arrival terminal (387 passengers) is the appropriate level--leaving only the 2 kilometers between stops 2 and 3 having a load above the desired occupancy. Hence, dividing 387 by 65 results in the required frequency of 5.95 (10 minute headway) for Method 4 as shown in Table 2.



## **Chapter 3: General Issues in Constructing Timetables**

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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 interpretation and explanation of each alternative. Undoubtedly, it is desirable that one of the alternatives will coincide with the scheduler's manual procedure. In this way the scheduler will be in a position not only to expedite his manual tasks but also to compare his methods with others regarding the trade-off between passenger comfort and operating cost.

### **3.1 Alternative Timetables**

The six objectives of this study, stated in Section 1.2, and current timetable construction procedures provide the basis to establish the spectrum of alternative timetables. Three

categories of options can be identified: (i) selection of type of headway, (ii) selection of a method or combination of methods for the setting of frequencies, and (iii) selection of special requests. These three groups of options are illustrated in Figure 3. A selected path in this figure provides a single timetable. Hence, there are a variety of timetable options.

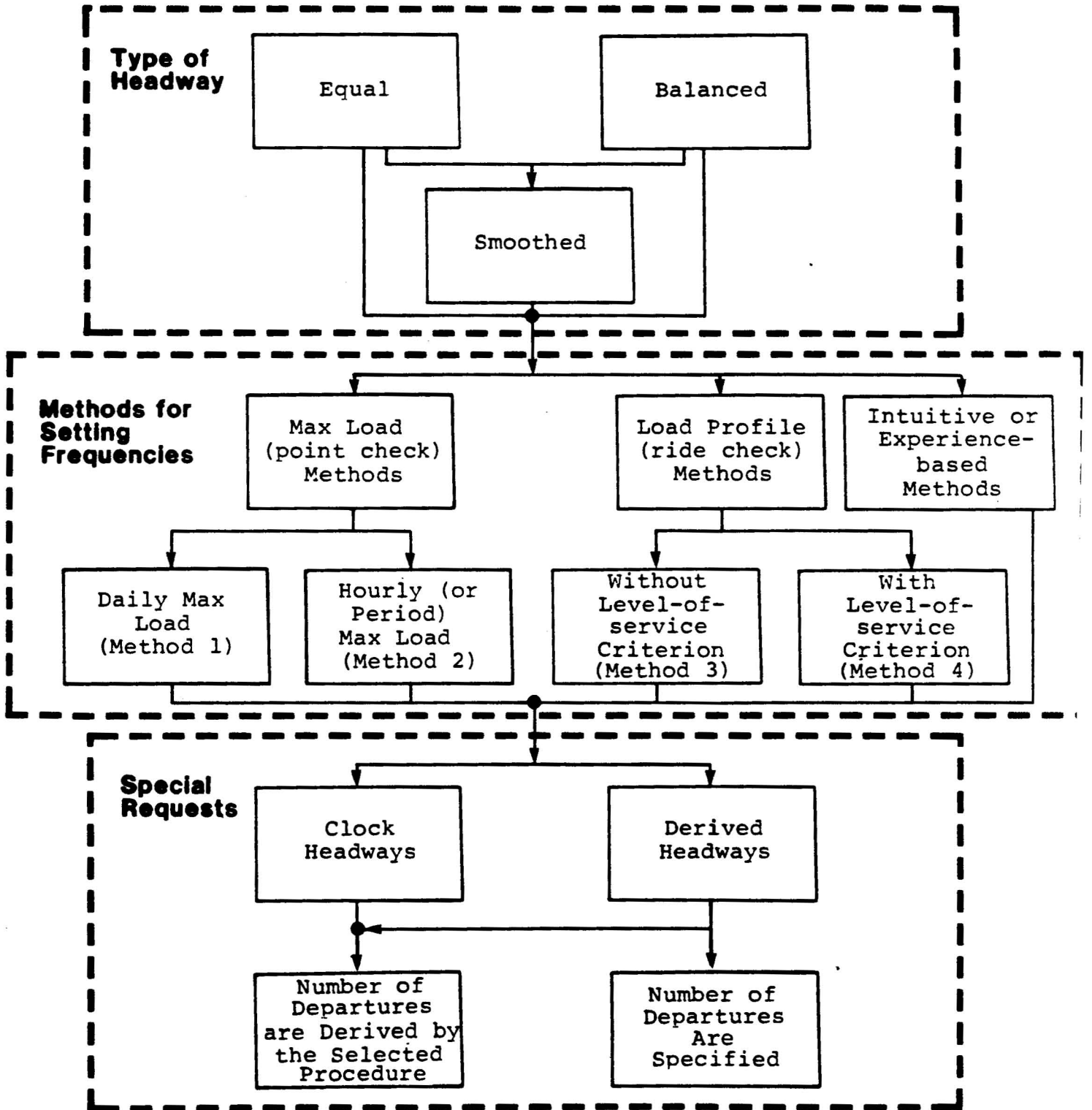
In the first category alternative types of headway are considered. An equal headway simply means constant time intervals between adjacent departures in each time period, or the case of evenly spaced headway. A balanced headway refers to unevenly spaced headways, in each time period, so that the observed passenger loads on all buses are similar. A smoothed headway is simply an average headway between the equal and the balanced headways. It is as an option in cases where the available data is not sufficient for concrete conclusions about balanced headways, but at the same time 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.

In the second category it is possible to select different frequency or headway determination methods. It allows for the selection of one method as well as combinations of methods for different time periods. The methods considered, indicated in Figure 3, are the two point check and two ride check methods described in Chapter 2. In addition, there might be procedures used by the scheduler which 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 timetables is the repetition of departure times, usually every hour. These easy-to-memorize departure times are based on the "clock headways": 1, 2, 3, 4, 5, 6, 7.5, 10, 12, 15, 20, 30, 40, 45 and 60 minutes. Note that headways less than 6 minutes are, generally, not considered by schedulers to influence the timing

Figure 3

ALTERNATIVE TIMETABLES



of passenger arrivals to a bus stop. However, for a general timetable construction procedure there might be peak periods in which the headways are less than 6 minutes 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 the time period. This request is most useful in crises where the scheduler need to supply a working timetable for operation based on tightly limited resources (buses and/or drivers). By using his intuitive 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.

Finally, it is important to emphasize that not all the paths in Figure 3 regarding clock headways are meaningful. Selection of balanced or smoothed headways can not be performed if there is a clock headway constraint. Also, as shown in Figure 3, the number of departures can not be specified for clock headways due to the specific time restrictions on those headways.

### 3.2 Comparison Measures

With computerized timetable construction, the scheduler can assess alternative timetables rather than examining only one. The detailed evaluation process will probably include short-turns and vehicle blocking considerations. However, two interrelated measures can be useful for the scheduler to

compare the alternative timetables: (i) number of required runs (departures), and (ii) required fleet size for a single route.

The first comparison measure, total number of departures, can serve as an indicator of the number of buses required, and also for simply examining whether or not it is possible to save bus runs. In a large bus property an efficient arrangement of vehicle blocks includes interlining (shifting a bus from one route to another) and deadheading trips. It is desirable to perform the procedures to construct timetables and vehicle blocking simultaneously. However, these two scheduling components are extremely cumbersome and, therefore, are treated separately. Consequently, when interlinings is allowed the first comparison measure serves only as a rough indicator of the required fleet size. After inserting each alternative timetable into the vehicle blocking procedure, it will be possible to predict the required number of buses.

The second comparison measure refers to each route separately and provides the required fleet size at the route level. It is based on a simple formula derived by Salzborn (Ref. 11) for a continuous time function and explicitly shown in Ceder (Ref. 4) for discrete time points. This formula states that if  $T$  is the round trip time including the layover and turn around time, then the minimum fleet size is the largest number of buses departing in any time interval of length  $T$ . Usually public timetables are divided into the two directions of travel for each route. Let  $N_a$  be the minimum fleet size, at the route level, for direction a and alternative timetable of type  $i$ , and  $N_b$  be the minimum fleet size for direction b and timetable  $j$ . The overall minimum required number of buses for the considered route is  $\max(N_a, N_b)$  for any selected  $i$  and  $j$  timetable types. Hence, the second comparison measure can be used for each direction separately and also for both directions when selecting the maximum of two derived values.

### 3.3 Anchoring the Timetable to a Single Timepoint

A public timetable usually consists of lists of bus departure times at all the route timepoints. Occasionally, this public timetable is given at just a single point -- the bus departure terminal. The running time across the timetable between adjacent timepoints may be varied from one time period to another, based on the ride check information. In essence, the timetable can be initially constructed at only one point, (this is usually the daily max load point,) and will be referred to as such and then extended forward and backward using the running time information. That is, in order to ensure an appropriate bus service to meet the variations of passenger demand it suffices to construct the timetable at one point. This observation can be stated in the following proposition:

#### Proposition

For a timetable consisting of more than one time point established by Method 2, the association of the maximum observed load in each time period with only a single timepoint ensures that the average bus load on each route segment is less than or equal to the desired occupancy.

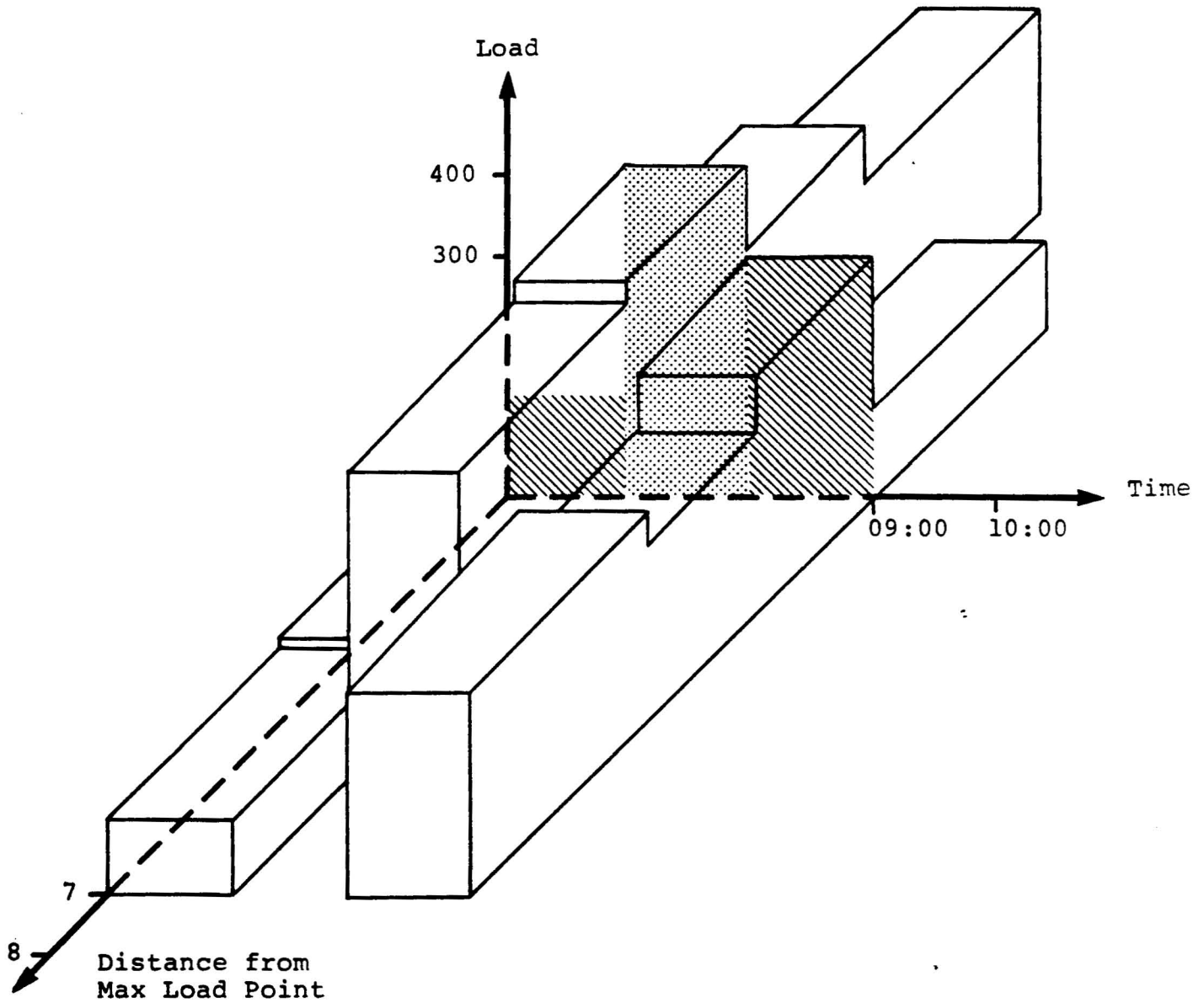
#### Proof and Interpretation

It suffices to show that the derived frequency is greater or equal to the maximum (across all route segments) required frequency in each time period. When considering only the daily max load point, it does not necessarily imply that the observed max load in each period occurs at that point. One can then treat the problem similarly to the three dimensional Time-Load-Distance representation in Figure 4. That is, the shaded three-part area in Figure 4 describes the max load of the example problem in each hour (see Section 2.3 and Figure 2) -- 132 (between 06:00-06:59), 411 (07:00-07:59), and 294 (08:00-09:00) passengers observed on-board. The accumulative

Figure 4

THREE DIMENSIONAL REPRESENTATION OF THE EXAMPLE LOAD  
PROFILES POSITIONED RELATIVE TO THE DISTANCE FROM THE  
MAX LOAD POINT

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observed load in each hour refers to the buses which pass (or depart) the daily max load point within the considered time period.

For the sake of clarity, Figure 5 shows six time-distance bus trajectories (this is a separate example than the one presented in Figure 4). Due to their passage times at the daily max load point, the first two trajectories refer to time period II and the remaining four - to period III. In Figure 5, the max load associated with period II is  $80 + 70 = 150$  (observed at timepoint A) and  $60 + 70 + 50 + 70 = 250$  in period III (at timepoint C). If the desired occupancy for periods II and III is 50 passengers then three departures will be set for period II and five - for period III at timepoint B. However, due to different running times in each period the headways at the daily max load point and the observed max load point do not necessarily coincide. If the timetable is set only at the daily max load point it certainly reflects the max required buses at the observed max load point. There is then a question as to whether the determined frequency at the actual max load point complies with the desired occupancy constraint.

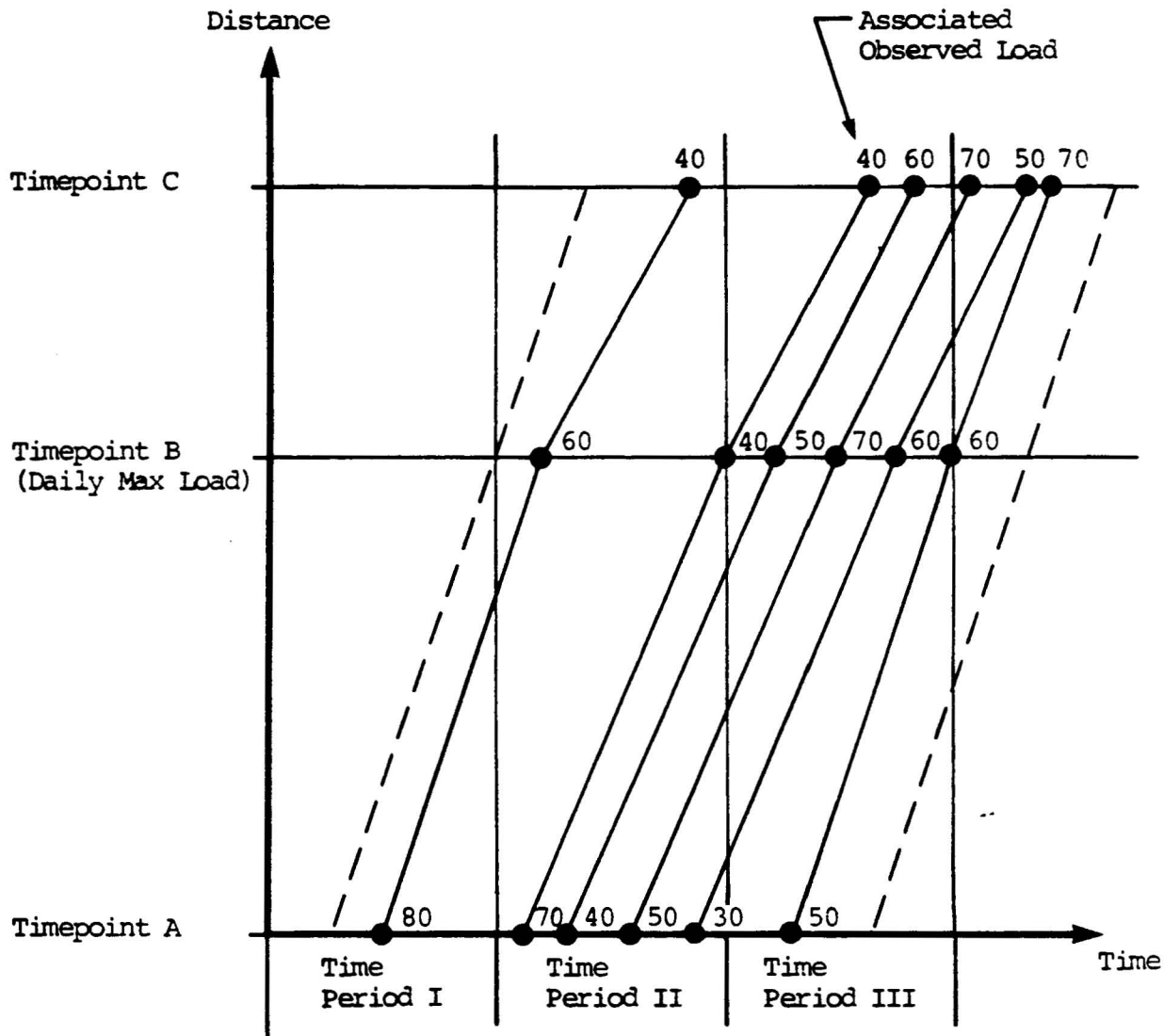
It is important to note that the running time information must rely on the fact that in an average sense buses do not overtake each other. Average running times should be determined not only from the ride check data but also from the requirement that the first bus to depart can not be the second to arrive to any timepoint. For example, the latter requirement is not always fulfilled in the manually performed procedure at SCRTD. Thus, the time-distance trajectories in Figure 5 can not cross each other in the average (deterministic) context.

Based on this note, the associated time span at the actual max load point which covers all the trips across the time period at the daily max load point, can be shorter (see the case in Figure 5) or longer than the time span of each time period. If the time span is shorter -- then the resultant frequency at the actual max load point will be higher than that at the daily max load point. Nonetheless, it will comply with



Figure 5

EXAMPLE OF TIME DISTANCE TRAJECTORIES OF ALL THE BUSES CROSSING THE DAILY MAX. LOAD POINT DURING PERIODS II AND III (STOP TIMES ARE NEGLECTED)



the desired occupancy constraint since the time-distance trajectories do not cross each other. If the time span is longer -- then the observed max load was accumulated over a longer period of time than the associated time period at the daily max load point, and will, therefore, result in a higher frequency at the daily max load point than at the actual max load point. In this second situation and due to the time-distance trajectories property, the loads will be less than or equal to the desired occupancy.

What remains to be shown is to explain and prove the proposition is that the overall number of departures at each timepoint is the same. This is a straightforward observation for the case with no short-turns. When short-turn trips (a trip is initiated beyond the regular departure terminal and/or terminated before the regular arrival terminal) are allowed the frequency can be reduced by the scheduler at any timepoint, except the observed max load point, provided that the desired occupancy constraint holds. This frequency reduction for short-turns can also be performed at the daily max load point for periods when it is not the time max load point.

Note that the above proposition can also be applied to Methods 3 and 4 -- each with its own loading constraints.

## **Chapter 4: Smoothing Procedures for Evenly Spaced Headways**

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One characteristic of existing timetables is the repetition of same headway in each time period with evenly spaced headways appearing every hour. The results of a method to set headways are served as a basis to establish the timetable. One of the problems facing the scheduler, while manually creating the timetable, is how to set the departure times in the transition segments between adjacent time periods. This chapter addresses this issue. Simple procedures are presented to smooth the transition between one (evenly spaced) headway to another for the variety of possible timetables outlined in Figure 3.

### **4.1 The Underlying Principle**

A common headways smoothing rule in the transition between time periods is to use an average headway. This simple rule is used by many bus properties and may result in either undesirable overcrowding or underutilization. For example, consider two time periods 06:00-06:59 and 07:00-08:00 in which the first bus is predetermined to depart at 06:00. In the first time period the desired occupancy is 50 passengers and in the second -- 70 passengers. The observed maximum demand to be considered in the first and second periods is 120 and 840 passengers, respectively. These observed loads at a single point are based on the uniform passenger arrival rate assumption (see the second paragraph in Section 2.3). The determined frequencies are  $120/50 = 2.4$  and  $840/70 = 12$  buses for the first and second

periods, and their associated headways are 25 and 5 minutes, respectively. Using the common average headway rule the transition headway is  $(25 + 5)/2 = 15$  minutes and, hence, the timetable is set to: 06:00, 06:25, 06:50, 07:05, 07:10, 07:15, ..., 07:55, 08:00. By assuming uniform passenger arrival rate the first period contributes to the bus departing at 07:05 the amount by  $(10/25) \times 50 = 20$  passengers for the remaining 10 minutes between 06:50 and 07:00 and the second period contributes  $(5/5) \times 70 = 70$  passengers. Consequently, the total expected number of passengers on the bus is  $20 + 70 = 90$  -- representing significant overcrowding. Certainly, one can argue that the uniform arrival rate assumption does not hold in reality. However, in some real life situation (e.g., after work and school dismissal) the observed demand in 5 minutes can be more than three times the observed demand in the previous 10 minutes as is the case in this example.

In order to eliminate, in an average manner, the occurrence of such situations the following objective is identified for the evenly spaced headways.

Objective: To set the departure time of the first bus in time period  $n$  so that its max load\* which is combined from a two-part demand at periods  $n-1$  and  $n$ , will comply with an average desired occupancy of the two period, where the timetable covers  $m$  periods:  $n=1,2,\dots,m$ .

This objective, in other words, is to set in the transition time an average desired occupancy rather than an average headway. To achieve this objective the following basic principle is used.

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\* If the frequency setting method is based on the load profile information (Methods 3 and 4) then instead of the max load the objective will be referred to a load which complies with the load profile method constraints.

Principle: For each time period determine the required bus frequency. In the transition time between periods combine the two frequencies so that the expected load is equal to the average derived occupancy.

This principle satisfies the objective as is demonstrated for the example presented above. Since the required frequency for the first time period is 2.4 buses, 0.4 buses are left after 06:50 to be combined with 0.6 more buses from the second time period. Hence, the 0.4 buses refers to a desired occupancy of 50 passengers while the 0.6 buses -- to 70 passengers. The slope, in terms of number of required buses per minute, for the second time period is  $12/60 = 0.2$  and the associated time for 0.6 buses is  $0.6/0.2 = 3$  minutes (after 07:00). Thus, the first bus in the second time period will depart at 07:03 and its desired occupancy (average load) is determined to be  $0.4 \times 50 + 0.6 \times 70 = 62$  passengers, as opposed to 90 passengers in the commonly used method. Further interpretation and examples of this principle are presented in the next two sections in which alternative timetables are derived for different combinations of possible paths in the Figure 3 flowchart.

#### 4.2 Employing Different Headway Setting Methods

The 3-hour example presented in Section 2.3 serves also as an example for the smoothing headways procedure. The basic data of that example appear in Tables 1 and 2. By applying the "average desired occupancy" principle it is possible to establish the alternative timetables for the case of evenly spaced headways. Three alternative timetables are constructed below for different headway setting methods: (i) applying Method 2, (ii) applying Method 4 with a 20% limit (on route length over which the average bus load exceeds the desired occupancy), and (iii) applying combination of methods -- Method 2 for off-peak periods and Method 4 (20% case) for the peak period.

(i) Method 2

In the 3-hour example the first trip is predetermined to depart at 06:00 and its loads are not considered in the analysis. From Table 2, using Method 2, the first and second determined headways are 23 minutes. Then, the "average desired occupancy" principle is applied for smoothing the headways in the transition from the first time period to the second. The use of the information given in Table 2 through a second smoothing process, enables one to construct the timetable shown in Table 3. Note that this timetable can be referred to the daily max load point (as in SCRTD) or to other timepoints (see Section 3.3). Table 3 includes the smoothing calculations for the sake of clarity. The last departure is assigned to 09:00 in order to comply with the required 4.52 buses between 08:00 and 09:00. That is, in rounding this frequency, five departures are required for that last time period. In an actual timetable the procedure continues to construct the departure times for the next time period.

The basic principle of the procedure can be demonstrated on a curve representing the cumulative frequency versus the time. The graphical representation of the example is exhibited in Figure 6 in which one can trace the derived departure times without calculation. This is completely equivalent to the procedure outlined in Table 3 and perhaps better illustrates the principle underlying the procedure.

In order to find the minimum fleet size (see Section 2.3) the round trip time information in Table 1 is used. For the first three departures in Table 3 one can add 55 minutes to check the number of departures that occur prior to the arrival of a considered trip. For example the third departure at 06:46 will return to its departure point at 07:41 and there are 6 departures (including the 06:46) that need to be covered by separate buses before the considered bus can initiate another trip (at 07:48). The fourth departure needs 67 minutes for a complete round trip and, hence, will be able to resume another

Table 3

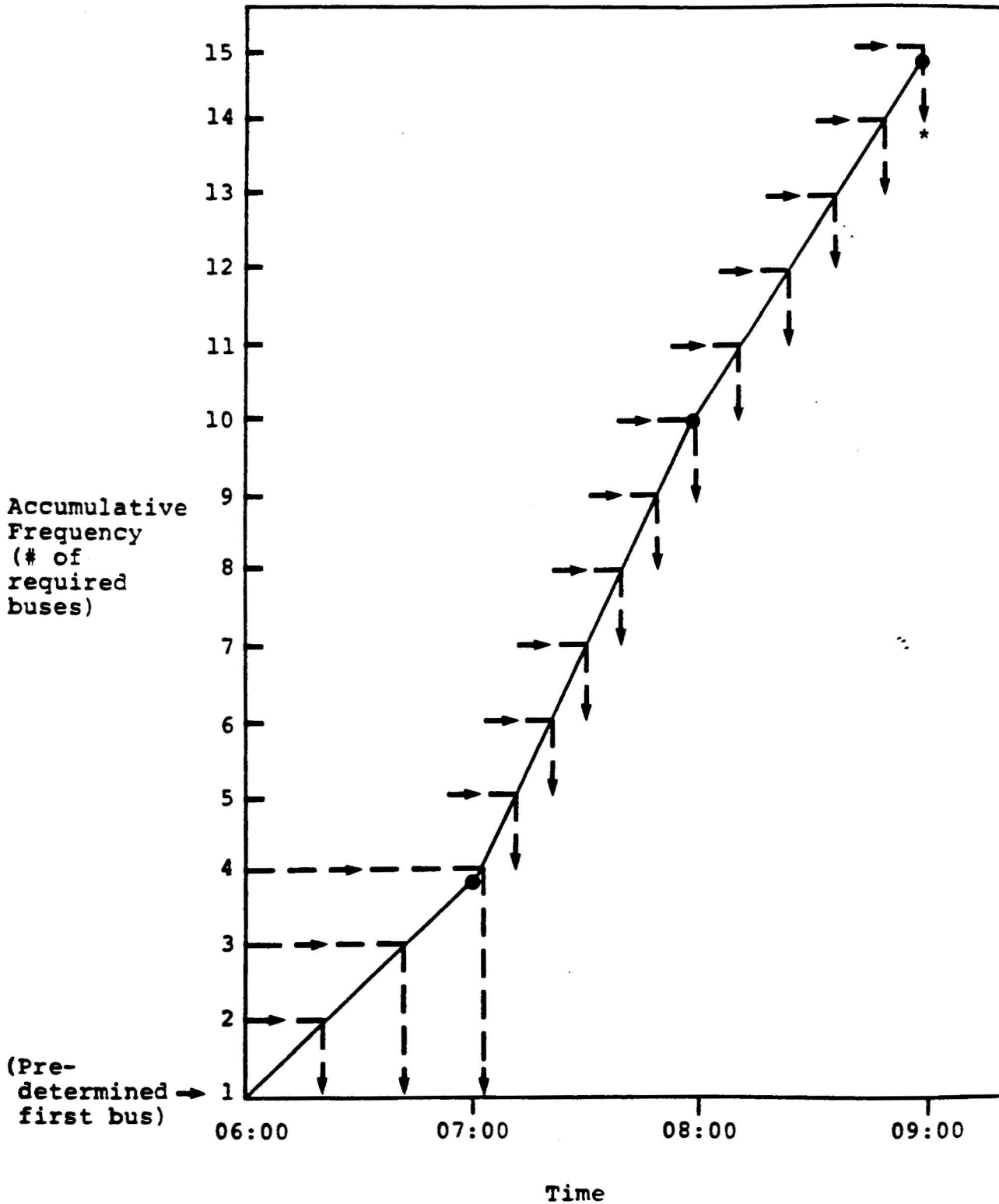
A TIMETABLE CONSTRUCTION PROCEDURE FOR THE CASE OF EVENLY SPACED HEADWAYS USING METHOD 2

	Smoothing #	Slope of Next Period (required buses per minute)	Remaining Bus Portion for Next Period	Minutes for the 1st Bus Departure After the Beginning of Next Period
Smoothing Procedure	1 <sup>st</sup>	$\frac{6.32}{60} = 0.105$	$1 - 0.64 = 0.36$	$\frac{0.36}{0.105} = 3.4$
	2 <sup>nd</sup>	$\frac{4.52}{60} = 0.075$	$(3 \times 0.105 = 0.32)$ $1 - 0.32 = 0.68$	$\frac{0.68}{0.075} = 9.1$
derived timetable	06:00*		07:21	08:09
	06:23		07:30	08:22
	06:46		07:39	08:35
	07:03		07:48	08:48
	07:12		07:57	09:00*
Comparison measures	Total number of departures = 15			
	Minimum (single route) fleet size = 8			

\*See text for these departures.

Figure 6

BASIC DETERMINATION OF DEPARTURE TIMES FOR EVENLY SPACED HEADWAYS IN EACH HOUR WITH A SMOOTHING PROCESS BETWEEN PERIODS



\*the last departure is set to 09:00 (see text)



departure from 08:10 and so on. The number of departures during these 67 minutes are 8. The fifth departure at 07:12 can resume another trip at 08:19 requiring 7 independent (each by a different bus) departures. Hence, according to the formula in Section 3.2, the minimum required fleet size for the example problem using Method 2 is 8 buses. The total number of departures in Table 3 is 15 but it is worth mentioning that some bus properties round up the derived frequency in constructing their timetable. Applying the latter procedure to the example problem (see Table 2) results in a total of  $1 + 3 + 7 + 5 = 16$  departures (including the first predetermined trip) as opposed to the 15 required departures using Method 2.

(ii) Method 4 (20% case)

Referring to the information indicated in the last two columns of Table 2. The timetable construction procedure, using Method 4, can be initiated by using the 25 minute headway before approaching the first smoothing process. The analysis is similar to that described for Method 2 and is presented in Table 4 along with the derived timetable and the comparison measures. The required frequency in Table 2 for the last time period is 4.2 and hence no additional departure is inserted at the end of the third period in Table 4. The procedure to derive the minimum required fleet size, reveals that the bus departs at 07:06 can initiate another trip at 08:13 and therefore there are 7 independent departures that must be performed by different buses. The remaining departures result in a required fleet size less than 7. The timetable derived by Method 4 requires two departures and one bus less than the timetable derived by Method 2. A graphical comparison between the frequency results of three methods is shown in Figure 7. The derived departure times for Method 3 and 4 can be obtained similarly to the procedure shown in Figure 6. That is, for each cumulative integer value of the required buses one can draw on horizontal line; at the intersection point between the selected curve and that line the associated departure time is

Table 4

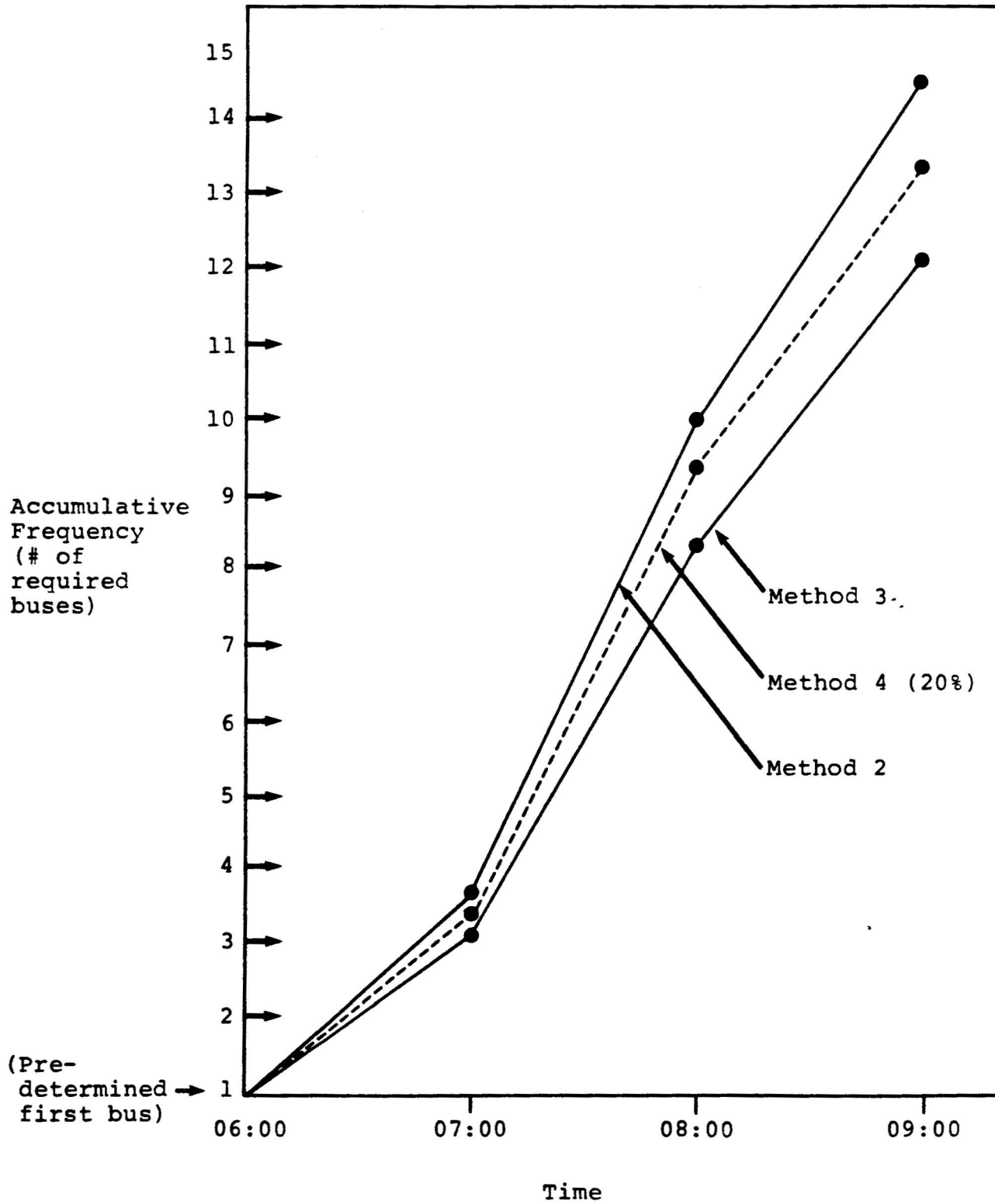
A TIMETABLE CONSTRUCTION PROCEDURE FOR THE CASE OF EVENLY SPACED HEADWAYS USING METHOD 4 (20% CASE)

	Smoothing #	Slope of Next Period (required buses per minute)	Remaining Bus Portion for Next Period	Minutes for the 1st Bus Departure After the Beginning of Next Period
Smoothing Procedure	1 <sup>st</sup>	$\frac{5.95}{60} = 0.099$	$1 - 0.38 = 0.62$	$\frac{0.62}{0.099} = 6.26$
	2 <sup>nd</sup>	$\frac{4.20}{60} = 0.07$	$(4 \times 0.099 = 0.4)$ $1 - 0.4 = 0.6$	$\frac{0.6}{0.07} = 8.6$
derived timetable	06:00*		07:26	08:23
	06:25		07:36	08:37
	06:50		07:46	08:51
	07:06		07:56	
	07:16		08:09	
Comparison measures	Total number of departures = 13			
	Minimum (single route) fleet size = 7			

\*First predetermined trip

Figure 7

COMPARISON OF THE ACCUMULATIVE FREQUENCY CURVE BETWEEN THREE FREQUENCY SETTING METHODS



determined. The derived timetable will then be based on the "average desired occupancy" principle described in the previous section.

### (iii) Combination of methods

Another option in selecting alternative timetables (see Figure 3) is to use different frequency setting methods for different time periods. In this way the scheduler can examine the effect of different frequency setting methods on the bus (resource) requirements during peak and off-peak periods. For example he may examine the use of Method 4 during peak periods in which the need for more buses is at its highest, and Method 2 for the off-peak periods.

In the example, Method 2 is applied to the first and third time periods while Method 4 (20% case) to the second (peak) period. The timetable construction procedure is similar to that outlined in Table 3 and 4. Table 5 presents the results of using the combination of methods along with the smoothing process. In the first transition the considered slope belongs to Method 4 while in the second transition the slope is of Method 2. In other words, if illustrating the cumulative frequency curve, the first segment will have a slope of  $2.64/60$  from 1 toward the value of  $2.64 + 1 = 3.64$ , then the second segment will have the slope of  $5.95/60$  toward the  $9.59 + 4.52 = 14.11$  value. By applying the two methods, the total number of departures is less by one and higher by one than that required for the timetables of Method 2 and 4, respectively. The minimum required fleet size is determined for the 07:04 departure to be 7 as opposed to 8 required buses when using only Method 2. The scheduler is now in a position to evaluate the possible savings resulting from applying the combination of methods.

### 4.3 Special requests

In Figure 3 two special requests are indicated. The first is to allow the use of "clock headways" and the second is to

Table 5

A TIMETABLE CONSTRUCTION PROCEDURE FOR THE CASE OF EVENLY SPACED HEADWAYS USING COMBINATION OF METHODS -- METHOD 2 FOR THE FIRST AND THIRD HOUR AND METHOD 4 (20%) FOR THE SECOND (PEAK) HOUR

	Smoothing ‡	Slope of Next Period (required buses per minute)	Remaining Bus Portion for Next Period	Minutes for the 1st Bus Departure After the Beginning of Next Period
Smoothing Procedure	1 <sup>st</sup>	$\frac{5.95}{60} = 0.099$	$1 - 0.64 = 0.36$	$\frac{0.36}{0.099} = 3.6$
	2 <sup>nd</sup>	$\frac{4.52}{60} = 0.075$	$(6 \times 0.099 = 0.6)$ $1 - 0.6 = 0.4$	$\frac{0.4}{0.075} = 5.33$
derived timetable	06:00* 06:23 06:46 07:04 07:14		07:24 07:34 07:44 07:54 08:05	08:18 08:31 08:44 08:57
Comparison measures	Total number of departures = 14 Minimum (single route) fleet size = 7			

\*First predetermined trip

prespecify the total number of departures in the timetable. Section 3.1 describes in detail the implications of these requests. Two timetables are constructed below to demonstrate the procedures to carry out the special requests: (i) applying Method 2 with clock headways, and (ii) applying Method 2 with specified 10 departures.

(i) Method 2 using clock headways

The frequency and headway results which are indicated in Table 2 for Method 3, are used to demonstrate the simple construction of a clock headway timetable. The first headway of 23 minutes is rounded down to its nearest clock headway of 20 minutes. The second headway of 9 minutes is rounded down to 7.5 minutes and the last headway of 13 minutes is rounded to 12 minutes. The only incompatibility is that the clock headway technique (see Section 3.1) includes a value of 7.5 minutes whereas most timetables do not allow non-integer minutes. The half minute can then be rounded alternately once up and once down in order to maintain the overall clock headway pattern. Table 6 shows that the derived timetable consists of 17 departures and a required fleet size of 9 buses which is determined at the 07:00 departure. One characteristic of the clock headway timetable is that the departure times repeat themselves each hour if the demand is not varied. If the time periods cover exact hours then there will be always a departure on the hour. If the end of a time period does not coincide with a departure time (very rare in practice) a smoothing procedure is needed to perform the transition from one clock headway to another. Additional bus departures may then be required to maintain the clock headway pattern. Therefore, it is likely that the scheduler will extend or shorten the time periods rather than tackling a clock headway transition problem. The comparison measures in Table 6 indicate that the clock headway timetable requires two more departures and one more bus than the results in Table 3 for which no special request is made.

Table 6

A DERIVED TIMETABLE FOR THE CASE OF EVENLY SPACED HEADWAYS USING METHOD 2  
WITH A SPECIAL REQUEST FOR CLOCK HEADWAYS

derived timetable	06:00*	07:15	07:53	08:48
	06:20	07:23	08:00	09:00
	06:40	07:30	08:12	
	07:00	07:38	08:24	
	07:08	07:45	08:36	
Comparison measures	Total number of departures = 17			
	Minimum (single route) fleet size = 9			

\*First predetermined trip

(ii) Method 2 with 10 departures specified

The prespecified number of departures directly affects the derived frequencies and headways. The total number of required buses using Method 2 (including the first predetermined departure) is  $1 + 2.64 + 6.32 + 4.52 = 14.48$ . Since it is required to construct only 10 departures the frequencies are modified proportionally by the ratio  $10/14.48 = 0.691$ . Table 7 includes the modified frequencies and headways. The procedure then continues the same way as without the special request. The construction of the timetable for the example problem appears in Table 7. The modified frequencies guarantee that the results will attain the specified number of departures while ensuring that the average load for all the time periods increases by the ratio  $1/0.691 = 1.45$ . This is equivalent to changing the desired occupancy from 50 to  $50/0.691 = 72$  passengers and from 65 to 94 passengers. Certainly, if the demand remains the same the scheduler should recognize the potential risk of overcrowding when he is restricting the total number of departures. Nevertheless, the purpose of this special request (see Section 3.1) is to have a systematic computerized, procedure to manage both crisis situations (limited resources) and situations in which additional passenger demand can be attracted (allowing more departures than strictly required).



Table 7

A TIMETABLE CONSTRUCTION PROCEDURE FOR THE CASE OF EVENLY SPACED HEADWAYS  
USING METHOD 2 WITH 10 DEPARTURES SPECIFIED

	Time Period	Frequency	Headway (minutes)	
modified frequency and headway	06:00 - 06:59	$2.64 \times 0.691 = 1.82$	33	
	07:00 - 07:59	$6.32 \times 0.691 = 4.37$	14	
	08:00 - 09:00	$4.52 \times 0.691 = 3.12$	19	
Smoothing Procedure	Smoothing #	Slope of Next Period (required buses per minute)	Remaining Bus Portion for Next Period	Minutes for the 1st Bus Departure After the Beginning of Next Period
	1 <sup>st</sup>	$\frac{4.37}{60} = 0.07$	$1 - 0.82 = 0.18$	$\frac{0.18}{0.07} = 2.6$
2 <sup>nd</sup>	$\frac{3.12}{60} = 0.05$	$(1 \times 0.07 = 0.07)$ $1 - 0.07 = 0.93$	$\frac{0.93}{0.05} = 18.6$	
derived timetable	06:00*	07:45		
	06:33	07:59		
	07:03	08:19		
	07:17	08:38		
	07:31	08:57		
Comparison measures	Total number of departures = 10 (as specified)			
	Minimum (single route) fleet size = 5			

\*First predetermined trip

## **Chapter 5:**

# **Procedures for Balancing Passenger Load When Allowing Unevenly Spaced Headways**

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ture times, by relaxing the evenly spaced headways pattern, in order to better match them with the observed passenger loads. It is a well-known fact that passenger demand varies even within a single time period, reflecting the business, industrial, educational, cultural, social and recreational transit needs of the community. This dynamic behavior provides a basis for the scheduler to adjust the departure times. These adjustments are presently based on (a) information supplied by road supervisors, (b) actual point and the ride check data, and (c) the scheduler's own intuition. Moreover, the availability of ADCS forms the framework to investigate the variation of passenger demand systematically. With the anticipated vast amount of passenger load data from the ADCS it will be possible to better match the bus departure times with the variable demand. The procedures to carry out this endeavor are addressed in this chapter. Similarly to Chapter 4, the procedures treat a variety of possible combinations of timetables as outlined in Figure 3.

### **5.1 Principle of the Approach**

A simple example is illustrated here in order to illustrate the underlying load balancing problem. Consider an evenly spaced headway timetable in which buses depart every 20 minutes between 07:00 and 08:00 i.e., at 07:20, 07:40 and

08:00. The observed load data consistently show that the second bus, which departs at 07:20, has significantly more passengers than the third bus. The observed (average) max load during this 60 minutes period is 150 passengers and the desired occupancy is 50 passengers. Hence, using Method 2, three buses are required to serve the demand as is the case in the evenly spaced headways timetable. The average observed max loads the three buses are 50, 70 and 30 passenger, respectively. If the scheduler believes that these average loads are consistent, then he will adjust the departure times so that each bus has a balanced load of 50 passengers on the average. The assumption of uniform passengers arrival rate results in  $70/20 = 3.5$  passenger/minute between 07:20 and 07:40, and  $30/20 = 1.5$  passengers/minute between 07:40 and 08:00. If the departure time of the second bus is shifted by X minutes backward (an early departure) then the equation  $(20 - X)3.5 = (20 + X)1.5$  yields the balanced schedule with  $X = 8$  minutes, or departures at 07:20, 07:32 and 08:00.

The procedure to balance the loads for many time periods and bus routes becomes cumbersome and time consuming to do manually, particularly when simultaneously attempting to balance the loads on individual buses and smooth the headways in the transition between time periods. Consequently, schedulers shift the departure times only intuitively without any systematic method to guarantee balanced loads based on the data. Often these shifts are taking place in situations of short turns in which the scheduler knows in advance that with evenly spaced headways, at the maximum load point, the short-line will carry less passengers than a regular trip which covers the entire route. The following objective is identified for the development of a procedure to guarantee balanced loads.

Objective: to set the departure time of each bus in a given time period so that its max load\* will approach the desired occupancy associated with that period.

The objective, in other words, is to shift departure times so that instead of being evenly spaced they will be unevenly spaced to obtain even loads at the max load point instead of the observed uneven loads. To achieve this objective the following basic principle is used.

Principle: For each observed bus departure, determine the uniform arrival rate of passengers at the max load point.\* Based on these rates, draw a cumulative curve of the observed max load\* on each bus with respect to its departure time. Construct the new departure times on the accumulative curve by coordinating the appropriate cumulative desired occupancy value and the time axis.

This principle satisfies the objective provided two basic assumptions: (a) the considered max load\* on each bus is a representative value of actual (average) observed max loads\*, (b) the passengers observed on-board at the max load point\* are accumulated at a uniform rate.

The first assumption is fulfilled when using the vast amount of data anticipated to be gathered from the ADCS, or when the schedulers have reliable sources of information provided by road inspectors and supervisors. Otherwise, a few load data observation on individual buses could reflect service problems such as bus bunching and should not be associated with the varied demand pattern. The second assumption usually holds when the observed headways are relatively small. For headways greater than 30 minutes further attention must be given to this assumption. Based on these two assumptions it is straightforward to prove that the "accumulative load" principle indeed satisfies the objective.

Referring to the example in the beginning of this section. A straight line can be drawn from 07:00 to 07:20 with a

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\* When Method 3 or 4 are considered to set the frequencies the load profile instead of the max load information is used.

slope of  $50/20 = 2.5$  passengers/minute, starting at zero load and ending at 50 where the y-axis is load and the x-axis is the time. Then from load 50 to load  $50 + 70 = 120$  a second line can be drawn with a 3.5 passengers/minute slope, and finally another line-toward the load 150 with a slope of 1.5 passengers/minutes. The time epoch on the curve associated with the first value (50 passengers) of the desired occupancy is 07:20 which means that the first departure is unchanged. The second time epoch associated with a load of 100 is 07:32 so that second bus will accommodate 50 instead of 70 passengers, and the third departure time remains at 08:00. The cumulative load curve also ensures that the first bus to depart in anytime period will accommodate the desired occupancy assigned to that period. Further interpretation and examples of the approach including the later remark, are presented in the next two sections.

## 5.2 Employing Different Headway Setting Methods with the Load Balancing Procedure

As in Chapter 4, the 3-hour example presented in Section 2.3 is used to illustrate in detail the load balancing procedure. However, the data in Table 1 and 2 are not sufficient to construct the timetable on the basis of individual buses.

Table 8 contains the complete data of the 3-hour example. The load indicated in Table 8 represent average loads associated with the scheduled departure times. It is possible that different departure times were observed for different buses though scheduled to depart at the same time (e.g., in each day across several days). In this case the observed (not the scheduled) average departure time should be used similar to the average load calculation. As mentioned in Section 2.3, the load on the first bus in each time period is divided proportionally in order to reflect the demand at the end of the previous time period and the beginning of the considered period. That is, in Table 1 the max load of the first period: 132 passengers is derived from the data in Table 8 (under Method 2):  $23 + 67 + (56 \times 15/20) = 132$ .

Table 8

COMPLEMENTARY DATA TO TABLE 1 ON THE BASIS OF INDIVIDUAL BUSES

Time Period	Departure Time	Elapsed Time From Last Departure (Headway)	Number of Passengers at the Daily Max. Load Point (Method 1)	Number of Passengers at the Hourly Max. Load Point (Method 2)	Load-Profile Area in Passenger-km (Method 3 & 4) and Divided by Route Length (in bracket)
06:00-06:59	06:00*	0	--	--	--
	06:25	25	18	23	160 (16.0)
	06:45	20	59	67	557 (55.7)
07:00-07:59	07:05	20	52	56	484 (48.4)
	07:15	10	58	63	542 (54.2)
	07:25	10	84	90	669 (66.9)
	07:35	10	89	91	751 (75.1)
	07:45	10	65	78	634 (63.4)
	07:55	10	60	55	520 (52.0)
08:00-09:00	08:10	15	54	60	525 (52.5)
	08:25	15	84	89	727 (72.7)
	08:40	15	87	81	636 (63.6)
	08:55	15	60	84	510 (51.0)

\*First predetermined trip

By applying the "cumulative load" principle it is possible to establish the alternative timetables for the case of unevenly spaced headways with balanced loads. Three alternative timetables are constructed below for different headway setting methods.

(i) Method 2

The procedure to construct the balanced load timetables appears in Table 9 along with the derived timetable and comparison measures. The graphical representation of this procedure is shown in Figure 8 for the whole 3 hours and with greater detail in Figure 9 which is an enlarged part of Figure 8. In Table 9 the uniform arrival rate is determined for each departure. Based on these rates and on the desired occupancy for each hour the headways are calculated in the last column of Table 9. As illustrated in Figure 9, the first departure is determined using two arrival rate slopes, as well as the second, third and fourth departure. The fifth departure, however, is constructed along a single slope. In the transition between time periods the desired occupancy is changed. The third departure time is determined through a preliminary check. The analysis first includes the possibility that the third departure time will be determined before 07:00. However, the calculation  $46/2.8 + 4/6.3 = 17.1$  which is rounded to a 17 minute headway beyond 6.49, leads to a departure time after 07:00. Hence, the calculation is changed to that indicated in Table 9, using the desired occupancy of 65 instead of 50. The timetable is based on rounding the headways to their nearest integer. A more conservative way is to always round down the headways so that the estimated load will be always by an increment below the desired occupancy. In the "round to the nearest integer" procedure there is a possibility to have an estimated load above the desired occupancy by an increment when rounding up the derived headways. This approach has been adopted because aside from the possibility of saving more bus runs, it reflects the fact that the desired occupancy is not a hard binding value.

Table 9

A TIMETABLE CONSTRUCTION PROCEDURE FOR BALANCING PASSENGER LOADS USING METHOD 2

	Observed Departure Times	# of Passengers (Method 2)	Uniform Passenger Arrival Rate (per minute)	Headway Calculations
The Balancing Loads Procedure	06:00*	--	--	--
	06:25	23	$\frac{23}{25} = 0.92$	$\frac{23}{0.92} + \frac{(50 - 23)}{3.35} = 33.1$
	06:45	67	$\frac{67}{20} = 3.35$	$\frac{40}{3.35} + \frac{10}{2.8} = 15.51$
	07:05	56	2.80	$\frac{4.6}{2.8} + \frac{19}{6.3} = 19.4$
	07:15	63	6.30	$\frac{44}{63} + \frac{21}{9} = 9.3$
	07:25	90	9.00	$\frac{65}{9} = 7.2, \frac{4}{9} + \frac{61}{9.1} = 7.1$
	07:35	91	9.10	$\frac{30}{9.1} + \frac{35}{7.8} = 7.8$
	07:45	78	7.80	$\frac{43}{7.8} + \frac{22}{5.5} = 9.51$
	07:55	55	5.50	$\frac{33}{5.5} + \frac{32}{4} = 14$
	08:10	60	4.00	$\frac{28}{4} + \frac{37}{5.93} = 13.2$
	08:25	89	5.93	$\frac{52}{5.93} + \frac{13}{5.4} = 11.2$
	08:40	81	5.40	$\frac{65}{5.4} = 12, \frac{3}{5.4} + \frac{62}{5.6} = 11.6$
08:55	84	5.60	$\frac{22}{5.6} = 3.9 **$	
derived timetable	06:00* 06:33 06:49 07:08 07:17		07:24 07:31 08:39 08:49 08:03	08:16 08:27 08:39 08:51 08:55
Comparison measures	Total number of departures = 15 Minimum (single route) fleet size = 7			

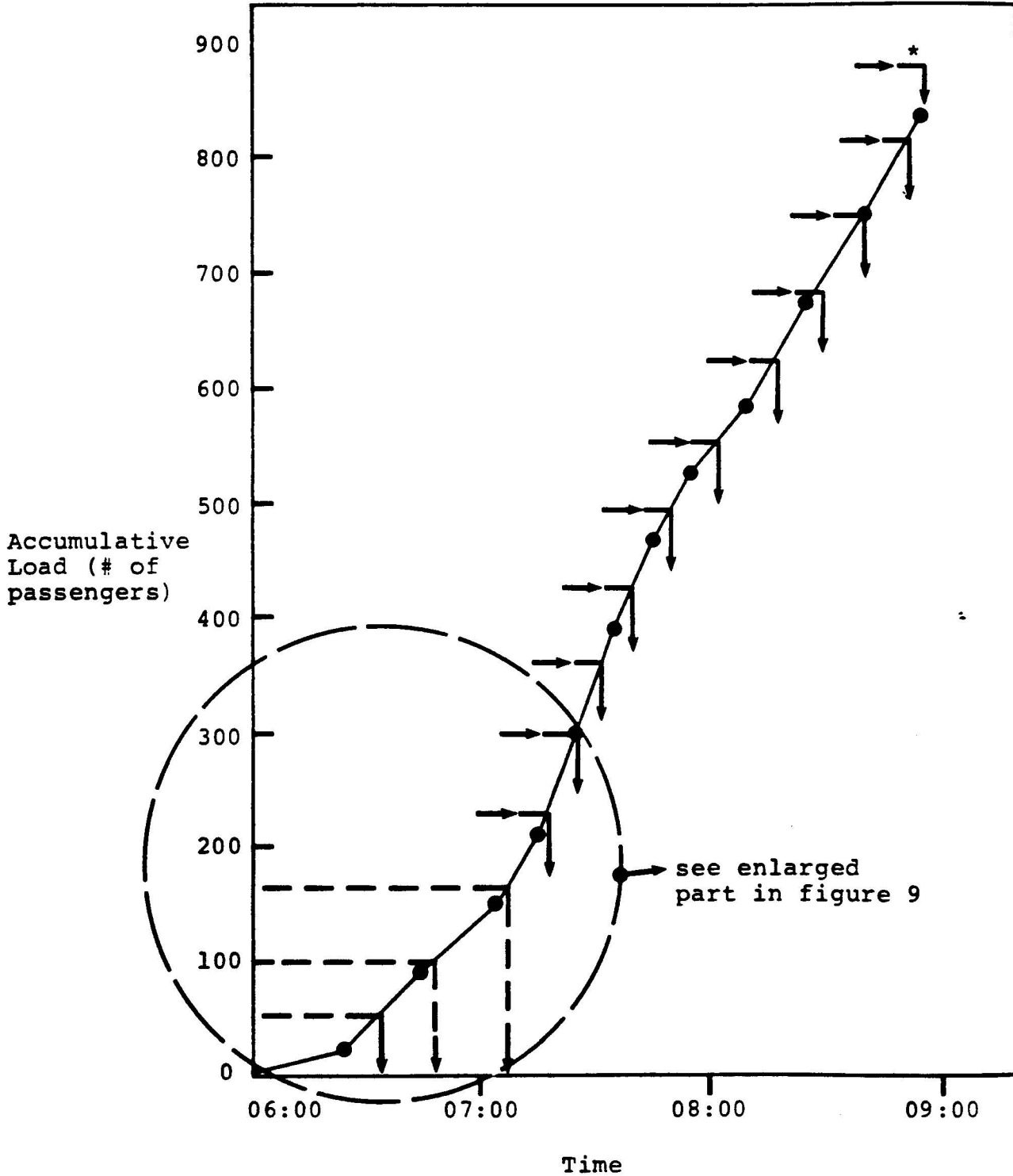
\*pre-determined first trip

\*\*correct only if the schedule terminates at 09:00, otherwise the procedure continues



Figure 8

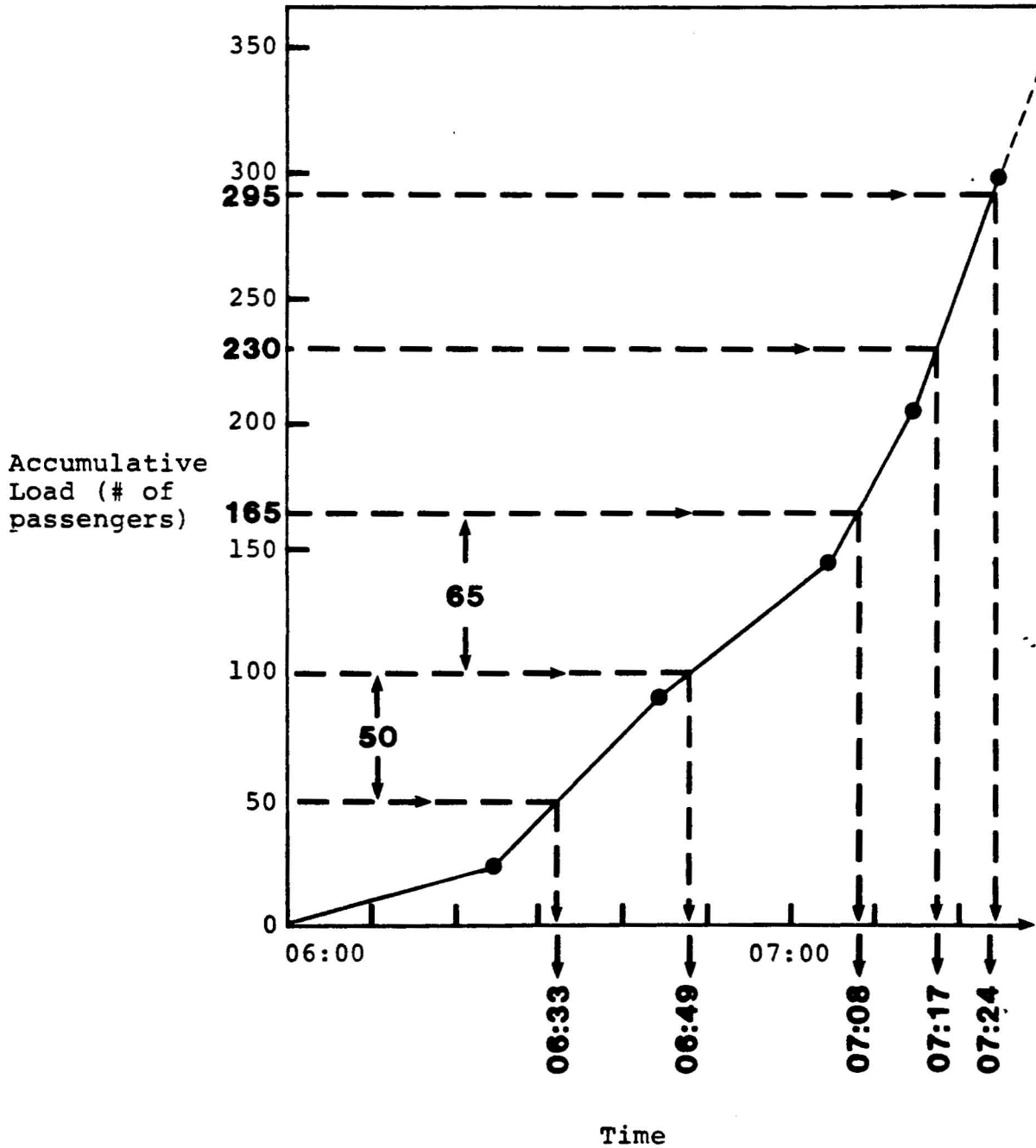
CUMULATIVE NUMBER OF PASSENGERS OBSERVED AT THE HOURLY  
MAXIMUM LOAD POINT (METHOD 2) AND THE DETERMINED BALANCED  
LOADS TIMETABLE



\*the last departure fits only to a schedule  
terminating at 09:00

Figure 9

ENLARGED PART OF THE CUMULATIVE LOAD CURVE FOR DETERMINATION OF DEPARTURE TIMES BASED ON BALANCING THE LOADS



The last departure of the derived timetable in Table 9 is based on the assumption that the service terminates at 09:00. As expected the balanced headway timetable contains the same number of departures as the evenly spaced headway timetable (Table 3). However, the rearrangement of the headways for balancing the loads on individual buses results in a required fleet size of 7 as opposed to 8 in Table 3. This minimum fleet size is attained at the 07:08 departure in the manner explained in Section 2.3 and 4.2.

(ii) Method 4 (20% case)

Based on the "cumulative load" principle it is possible to create the timetable using the frequency requirements for Method 4 (see Table 2). Recall that Method 4 (20% case) allows the average observed load to be above the desired occupancy (and equal to or below the bus capacity) along no more than 20% of the route length. The information given in the last column of Table 8 is used to construct a timetable which meets the frequency requirements for Method 4.

In Table 10 the procedure for balancing the average loads is described in detail. The average loads (based on the load-profile information) are subjected to a similar analysis Table 10 to that performed on the max loads when using Method 2. Instead of accumulating the desired occupancy, this procedure accumulates measures of an average number of passengers for each required bus by Method 4, as shown in Table 10. The graphical representation of this procedure is displayed in Figure 10. For the first hour each required bus from a total of 2.38 buses is assigned 45.4 passengers on the average which is equivalent to the load-profile area of  $45.4 \times 10 = 454$  passenger-km.

The second departure is determined to be 11 minutes after 06:25 and the third after an additional 17 minutes. In the transition between the first and the second time periods the average number of passengers for each required bus is changed

Table 10

A TIMETABLE CONSTRUCTION PROCEDURE FOR BALANCING PASSENGER LOADS USING METHOD 4 (204 CASE)

	Observed Departure Times	Average Loads (Method 4)	Uniform Passenger Arrival Rate (per minute)	Accumulative Load		Required # Of Buses	Average # Of Passengers For Each Required Bus	Headway Calculations
				For Each Departure	End Of Time Period			
The Balancing Loads Procedure	06:00*	--	--	--	--		--	--
	06:25	16.0	$\frac{16}{25} = 0.64$	16.0	$2.42 \times 15 + 71.7 = 108$	2.38	$\frac{108}{2.38} = 45.4$	$\frac{45.4 - 16}{2.78} = 10.57$
	06:45	55.7	$\frac{55.7}{20} = 2.78$	71.7				$\frac{71.7 - 45.4}{2.78} + \frac{18.7}{2.42} = 17.2$
	07:05	48.4	2.42	120.0				$\frac{143.5 - 120}{5.42} + \frac{120 - 108}{2.42} = 9.3$
	07:15	54.2	5.42	174.3				$\frac{174.3 - 143.5}{5.42} + \frac{26.5}{6.69} = 9.6$
	07:25	66.9	6.69	241.2				$\frac{241.2 - 200.8}{6.69} + \frac{16.9}{7.51} = 8.3$
	07:35	75.1	7.51	316.3			$\frac{449.2 - 108}{5.95}$	$\frac{57.3}{7.51} = 7.63$
	07:45	63.4	6.34	379.7	$3.5 \times 5 + 431.7 = 449.2$	5.95	= 57.3	$\frac{0.9}{7.51} + \frac{56.4}{6.34} = 9$
	07:55	52.0	5.20	431.7				$\frac{7}{6.34} + \frac{50.3}{5.2} = 10.8$
	08:10	52.5	3.50	484.2				$\frac{481.5 - 449.2}{3.5} = 9.2^{**}$
	08:25	72.7	4.85	536.9			$\frac{651.5 - 449.2}{4.2}$	$\frac{484.2 - 481.5}{3.5} + \frac{45.5}{4.85} = 10.1$
	08:40	63.6	4.24	600.5				$\frac{2.7}{4.85} + \frac{45.5}{4.24} = 11.3$
	08:55	51.0	3.40	651.5	651.5	4.20	= 48.2	$\frac{18.1}{4.24} + \frac{30.1}{3.4} = 13.1$ $\frac{20.9}{3.4} = 6.1^{***}$
	derived timetable	06:00 06:36 06:53 07:09 07:19		07:27 07:35 07:44 07:55 08:09		08:19 08:30 08:43 08:49***		
Comparison measures	Total number of departures = 14 Minimum (single route) fleet size = 7							

\*pre-determined first trip

\*\*these transition calculations are explained fully in the text

\*\*\*correct only if the schedule terminates at 09:00, otherwise the procedure continues

from 45.4 to 57.3 through an intermediate value of 52.7 as shown in Figure 10. In that transition  $1 - 0.38 = 0.62$  buses are required from the second time period to cover the fourth departure. That is,  $0.62 \times 57.3 = 35.5$  passengers are accumulated with 108 to obtain 143.5; then the third row of calculation in Table 10 determines the rounded 9 minutes to be added to 07:00 for the fourth departure time. In the transition between the second and the third time periods, one first checks if the tenth departure time falls before 08:00 :  $430 + 57.3$

449.2. Hence, this departure will be after 08:00 and  $5.95 - 5.62 = 0.33$  buses are left in the second period to be combined with 0.67 buses from the third period. That is,  $0.67 \times 48.2 = 32.3$  passengers to be accumulated with 449.2 to obtain 481.5; then the ninth row of calculation in Table 10 determines the rounded 9 minutes to be added to 08:00 for the tenth departure time.

The last departure is based on the assumption that the schedule is terminated at 09:00. Since this procedure treats average values of individual buses, the last departure appears to carry less passengers than the average and it is left to the scheduler to decide whether to allow this departure or to delay it past the end of the schedule horizon (09:00 in the example). This last departure makes the difference between the 13 required departures using the equal headway timetable (Table 4) and that indicated in Table 10.

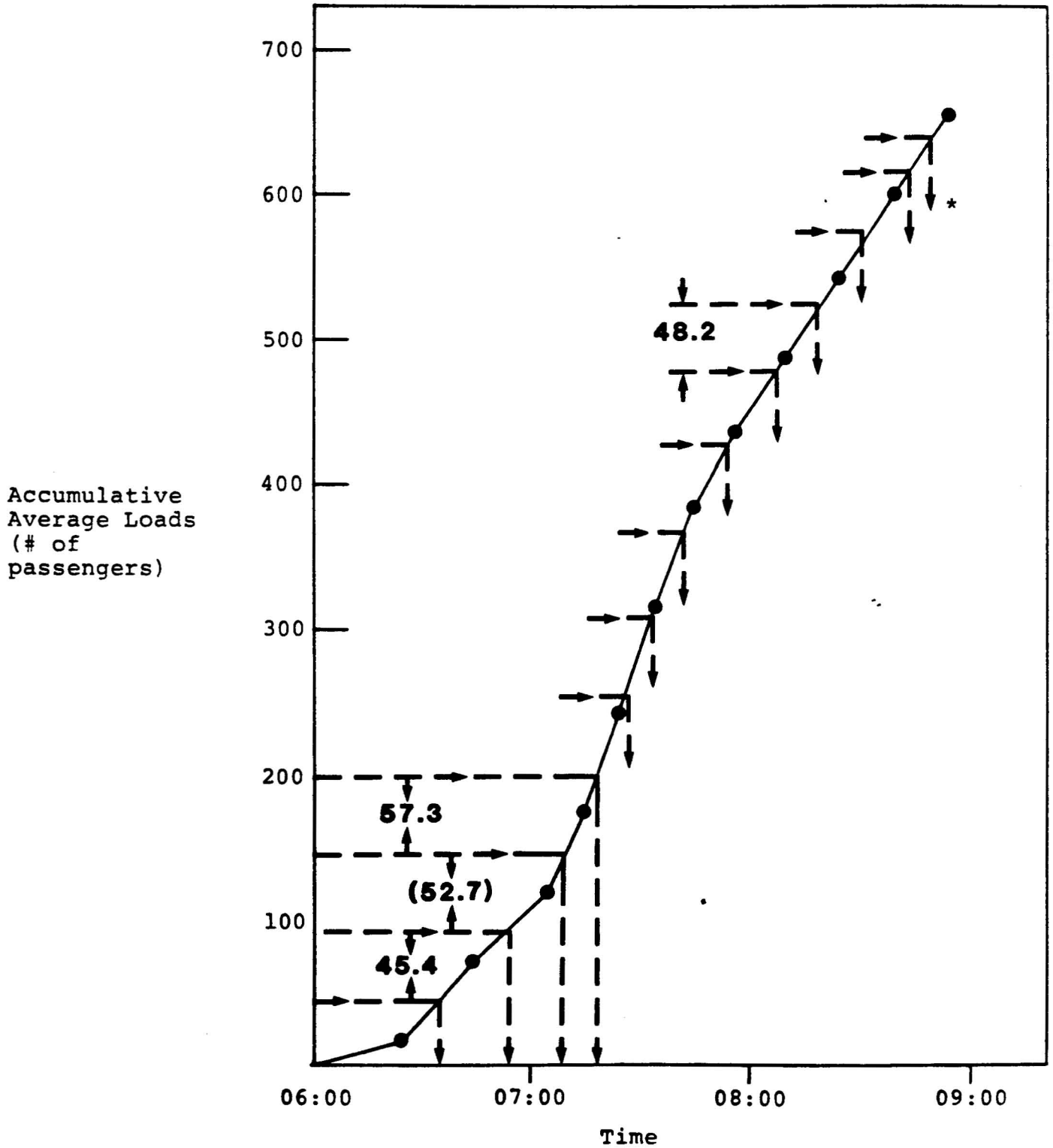
### (iii) Combination of Methods

Another option to be examined in the selection of alternative timetables is to use a combination of frequency setting methods. Similar to that performed in Section 4.2, the first and third hours are subjected to the frequency requirements of Method 2: 2.64 and 4.52 buses, respectively, while the second (peak) hour is treated by the required 5.95 buses of Method 4.

The analysis is shown in Table 11 using the "cumulative load" principle. The described procedure in this table is

Figure 10

BASIC DETERMINATION OF DEPARTURE TIMES FOR BALANCING THE LOADS  
USING METHOD 4 (20% CASE)



\*the last departure time is appropriate only to a schedu  
terminating at 09:00

similar to that presented in Table 10 for Method 4. The only exception is that the required number of buses are of mixed values from Methods 2 and 4. In the transition between the first and the second time periods  $1 - 0.64 = 0.36$  buses are required from the second time period to cover the fourth departure. That is,  $0.36 \times 57.8 = 20.6$  passengers to be accumulated with 126.3 to obtain 147.1 which is used in Table 11 in the third row of calculation to determine the 07:07 departure. Similar to that the transition between the second and the third time periods requires four separate calculations:  $5.95 - 5.36 = 0.59$ ,  $0.59 \times 69.5 = 41$ ,  $41 + 470 = 511$  and the last one appears in the ninth row of calculation in Table 11 to determine the departure 10 minutes after 08:00.

### 5.3 Special Request and Smoothed Headways

Only one of the two special requests indication in Figure 3 can be fulfilled along with the procedure for balancing the loads. As is mentioned in Section 3.1 timetables with clock headways can not incorporate uneven headways. Therefore, when approaching even loads through uneven headways it is only possible to specify the number of departures. In Figure 3 three types of headways are shown: equal, balanced and smoothed. The first two have been treated in Chapter 4 and in this chapter. The construction of a timetable for the third type is shown in the second part of this section following the description of balanced headways with a prespecified number of departures.

#### (i) Method 2 with specified 10 departures

The implications of this special request are indicated in Section 3.1. From Table 2 the total number of required buses for the example problem using Method 2 is 14.48 including the first predetermined departure. Since it is required to create only 10 departures the frequencies are modified proportionally by the ratio  $10/14.48 = 0.691$  similar to the analysis in Section 4.3.

Table 11

A TIMETABLE CONSTRUCTION PROCEDURE FOR BALANCING PASSENGER LOADS USING COMBINATIONS OF METHODS -- METHOD 2 FOR THE FIRST AND THIRD HOUR AND METHOD 4 (201) FOR THE SECOND (PEAK) HOUR

	Observed Departure Times	Number of Passengers (Max-Method 2 Average-Method 4)	Uniform Passenger Arrival Rate (per minute)	Accumulative Load		Required # Of Buses	Number of Passengers For Each Required Bus	Headway Calculations
				For Each Departure	End Of Time Period			
The Balancing Loads Procedure	06:00*	--	--	--	--	--	--	--
	06:25	23	$\frac{23}{25} = 0.92$	23	$2.42 \times 5 + 90 = 126.3$	Method 2 2.64	$\frac{126.3}{2.64} = 47.8$	$\frac{47.8 - 23}{3.35} = 7.4$
	06:45	67	3.35	90				$\frac{90 - 47.8}{3.35} + \frac{5.6}{2.42} = 14.9$
	07:05	48.4	2.42	138.4				$\frac{147.1 - 138.4}{5.42} + \frac{138.4 - 126.3}{6.69} = 10.1$
	07:15	54.2	5.42	192.6		Method 4		$\frac{192.6 - 147.1}{5.42} + \frac{12.3}{6.69} = 10.1$
	07:25	66.9	6.69	259.5			$\frac{470 - 126.3}{5.95}$	$\frac{54.6}{6.69} + \frac{3.2}{7.51} = 8.6$
	07:35	75.1	7.51	334.6				$\frac{57.8}{7.51} = 7.7$
	07:45	63.4	6.34	398.0	$4 \times 5 + 450 = 470$	5.95	= 57.8	$\frac{14.1}{7.51} + \frac{43.7}{6.34} = 8.8$
	07:55	52.0	5.20	450.0				$\frac{19.7}{6.34} + \frac{38.1}{5.2} = 10.4$
	08:10	60	4.00	510		Method 2		$\frac{511 - 510}{5.93} + \frac{510 - 470}{4} = 10.2$
	08:25	89	5.93	599			$\frac{764 - 470}{4.52}$	$\frac{69.5}{5.93} = 11.7$
	08:40	81	5.40	680		4.52		$\frac{599 - 511 - 69.5}{5.93} + \frac{51}{5.4} = 11.7$
	08:55	84	5.60	764	764		= 69.5	$\frac{30}{5.4} + \frac{39.5}{5.6} = 12.6$ $\frac{44.5}{5.6} = 7.9^{***}$
	derived timetable	06:00* 06:32 06:47 07:07 07:17		07:26 07:34 07:43 07:53 08:10		08:22 08:35 08:48 08:56***		
Comparison measures	Total number of departures = 14 Minimum (single route) fleet size = 7							

\*pre-determined first trip.  
 \*\*these transition calculations are explained fully in the text.  
 \*\*\*correct only if the schedule terminates at 09:00, otherwise the procedure continues.



The procedure is described in Table 12 in which the desired occupancy is modified by the 0.691 ratio. The "cumulative load" principle is applied to obtain the derived headways. The second headway determination is based on the modified desired occupancy of 72.4. However, since this headway results in a departure time beyond 07:00 the modified occupancy of 94.1 is considered to determine the 07:09 departure. Due to some rounding of the frequencies and the modified desired occupancy 11.8 passenger are "left" toward the end of the example time horizon. The computer program described in the next chapter overcomes this discrepancy and provides exact number of departures as specified.

(ii) Smoothed headways

In some cases the schedulers have their own reasons to believe that equal headways will result in significant uneven loads on individual buses. However, at the same time they neither have sufficient data to form a statistical evidence for average loads on each bus nor they have their own information that the data can represent individual buses. In such cases the scheduler can request from the computerized system an "average" timetable between the equal and the balanced timetables.

This "average" timetable is constructed simply by calculating average headways. Table 13 summarizes the procedure to smooth the balanced headway toward the equal headway. Whenever the average value is characterized by 1/2 minute the procedure rounds it toward the equal headway departure time.

Table 12

A TIMETABLE CONSTRUCTION PROCEDURE FOR BALANCING PASSENGER LOADS USING METHOD 2 WITH SPECIFIED 10 DEPARTURES

	Observed Departure Times	# of Passengers (Method 2)	Uniform Passenger Arrival Rate (per minute)	Modified "Desired" Occupancy	Headway Calculations
The Balancing Loads Procedure	06:00*	--	--	--	--
	06:25	23	$\frac{23}{25} = 0.92$	$\frac{50}{0.691} = 72.4$	$\frac{23}{0.92} + \frac{72.4 - 23}{3.35} = 39.7$
	06:45	67	3.35		$\frac{17.6}{3.35} + \frac{56}{2.8} + \frac{20.5}{6.3} = 28.51^{**}$
	07:05	56	2.80		$\frac{42.5}{6.3} + \frac{51.6}{9} = 12.48$
	07:15	63	6.30		$\frac{38.4}{9} + \frac{55.7}{9.1} = 10.4$
	07:25	90	9.00		$\frac{35.3}{9.1} = \frac{58.8}{7.8} = 11.4$
	07:35	91	9.10	$\frac{65}{0.691} = 94.1$	$\frac{19.2}{7.8} + \frac{55}{5.5} + \frac{19.9}{4} = 17.4$
	07:45	78	7.80		$\frac{40.1}{4} + \frac{54}{5.93} = 19.1$
	07:55	55	5.50		$\frac{35}{5.93} + \frac{59.1}{5.4} = 16.8$
	08:10	60	4.00		$\frac{21.9}{5.4} + \frac{72.2}{5.6} = 16.9$
	08:25	89	5.93	$\frac{65}{0.691} = 94.1$	$\left( \frac{11.8}{5.6} = 2.1 \right)^{**}$
	08:40	81	5.40		
	08:55	84	5.60		
derived timetable	06:00* 06:40 07:09 07:21 07:31		07:42 07:59 08:18 08:35 08:52		
Comparison measures	Total number of departures (as required) = 10 Minimum (single route) fleet size = 5				

\*pre-determined first trip

\*\*see explanations in text

Table 13

A TIMETABLE CONSTRUCTION PROCEDURE FOR A SMOOTHED (BETWEEN BALANCED AND EQUAL) HEADWAYS CASE USING METHOD 2

	Equal Headways Timetable (See Table 3)	Balanced Headways Timetable (See Table)	Headway Calculations
The Average Procedure For Smoothed Headways	06:00*	06:00	--
	06:23	06:33	$\frac{33 - 23}{2} + 23 = 28$
	06:46	06:49	$\frac{49 - 46}{2} + 46 = 47.5$
	07:03	07:08	$\frac{8 - 3}{2} + 3 = 5.5$
	07:12	07:17	14.5
	07:21	07:24	22.5
	07:30	07:31	30.5
	07:39	07:39	--
	07:48	07:49	48.5
	07:57	08:03	$\frac{63 - 57}{2} + 57 = 60$
	08:09	08:16	12.5
	08:22	08:27	24.5
	08:35	08:39	37
	08:48	08:51	49.5
	09:00	08:55	57.5
derived timetable	06:00* 06:28 06:47 07:05 07:14	07:22 07:30 07:39 08:48 08:00	08:12 08:24 08:37 08:49 08:57
Comparison measures	Total number of departures = 15 Minimum (single route) fleet size = 7		

## **Chapter 6: Computer Programs and Test Runs on a SCRTD Route**

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This chapter incorporates all the major issues that are covered in the previous five chapters. It demonstrates the final product of the analysis so that all the study objectives, set forth in Section 1.2, are fulfilled. The product is a set of computer programs that perform:

- (i) conversion from the bus property mainframe files to an adequate input files
- (ii) analysis of four methods for setting bus frequencies
- (iii) creation of alternative timetables at the daily max load point, and
- (iv) creation of a public timetable at all the route timepoints.

Recent ride check data from SCRTD line 217 which was obtained in tape form is used to demonstrate the programs. The use of real-life data enables the possibility to study the full range of the programs' implementation potential.

### **6.1 Description of the Programs**

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

Program I -- setting frequencies and headways by four methods

Program II -- setting alternative bus departure times at one time-point

The full description of the input to these two programs is indicated in Appendix A and Appendix B, respectively. The basic user input to Program I consist of:

- route (line) number
- bus type
- direction of travel
- bus capacity (number of seats & max allowable standees)
- number of time periods
- each stop (or time point name)
- distances between each adjacent stops (or time-points) along the route
- number of observed departure 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
- loads between each two stops (or timepoints) -- averages are preferred in each planning period, i.e., Mon.-Fri., Sat., Sun. and holidays, exceptions.

The basic input to Program II consists of:

- time periods' description including their length
- round trip time including layover and turn around times in each time period
- the determined (non-integer) frequencies from Program I including possible user changes and additional frequencies (e.g., inserted by the scheduler) for each time period.
- observed average departure (or passage) times for each individual bus at the timepoint in which the timetable is created (usually at the daily max load point)

- observed average headway for each bus
- observed average loads for each bus based on the selected frequency setting methods (e.g., its load at the daily max load point for Method 1, its load at the hourly max load point for Method 2, its load-profile are for Methods 3 and 4)

A schematic overview of the computerized system is shown in a flowchart in Figure 11. This flowchart, aside from describing the programs, advises the user on the various available options. It is anticipated that the initialization will be at the mainframe computer files of a bus property. In the test runs to be described in the remainder sections of this chapter, the SCRTD files are used. A conversion program has been written to prepare the adequate input data for Program I and II. This program assumes that a ride check data is available on the bus property files. The conversion program is fully described in Appendix C.

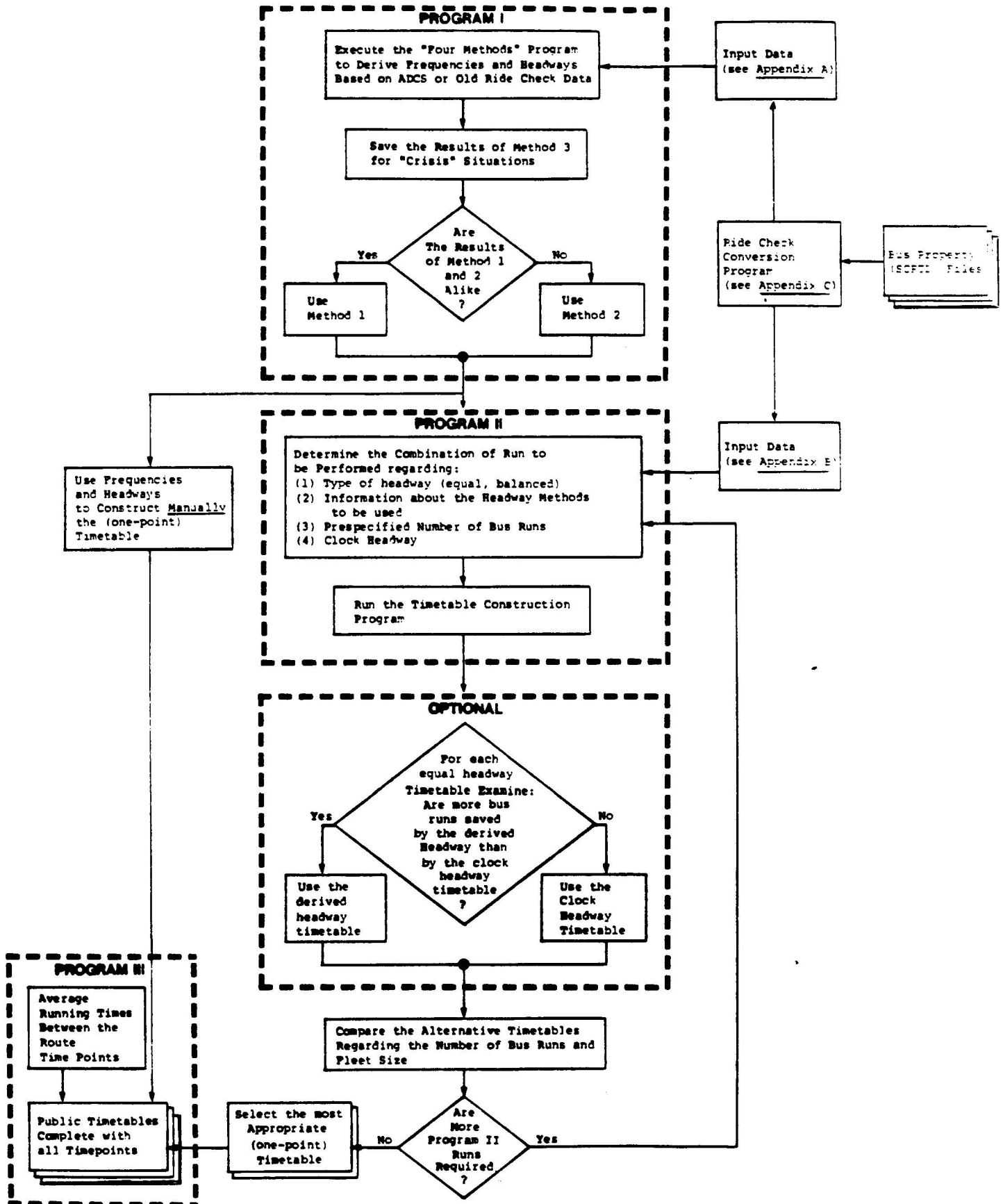
The analyses made by Program I are explained in Chapter 2 and further interpreted in Reference 4. In Figure 11 the user is advised to save the low frequencies of Method 3 for situations in which the service must be provided but the amount of resources is restricted. The results of Method 1 and 2 are then compared by a statistical (chi-square) test as is demonstrated on the SCRTD line in the next section. Nevertheless, Program II can include as many frequency results as the user wishes and the comparison between Method 1 and 2 serves only as a suggested approach.

In Program II the user can request various alternative timetables according to the options indicated in Figure 3. For each computer run using Program II, the user simply keypunches his requests as follows:

- (i) "number" of methods to be used (among the inserted frequency setting methods).
- (ii) for each used method the user specifies:

Figure 11

FLOW CHART OF PROGRAM I (SETTING ALTERNATIVE FREQUENCIES AND HEADWAYS) AND PROGRAM II (CONSTRUCTING ALTERNATIVE TIMETABLES)



- method "number"
  - the time period "number" in which to start using the method
  - the 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
- (iv) clock headway -- "0" for not required  
-- "1" for required
- (v) prespecified number of departures  
-- "0" for no need  
-- "given number" of departures for using the constraint.

The smoothed headway timetable, as is explained in Section 5.3, is constructed from two derived timetables and presently (temporarily) is part of Program III. For the equal headway timetable an optional decision exists about the comparison between the derived and the clock headways as is shown in Figure 11. Program III simply extends the derived timetable at one point to all the other timepoints in order to complete the information needed for the public. Finally, Figure 11 indicates that there is always a possibility to construct manually the timetable based on the derived headways by Program I.

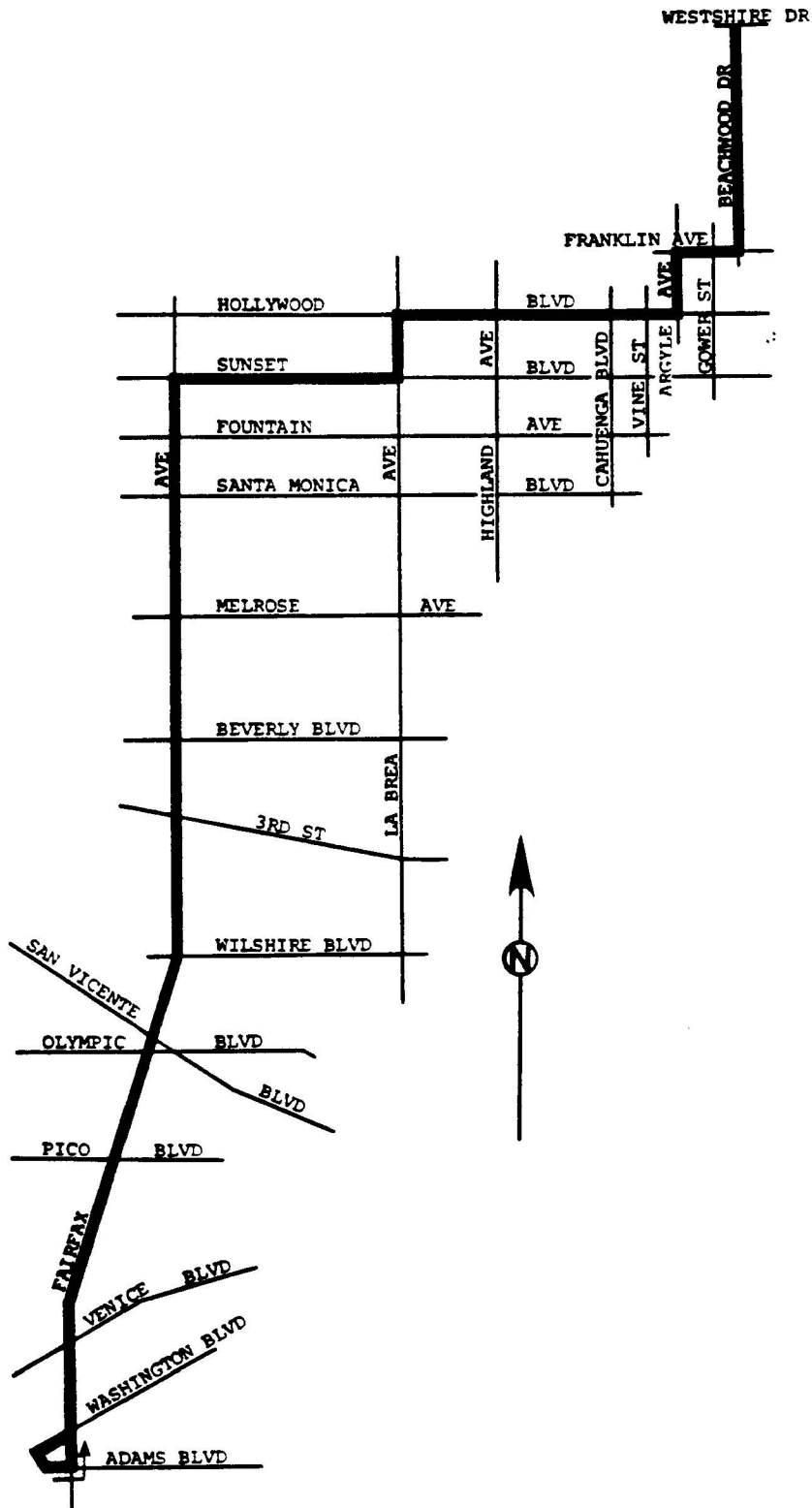
## 6.2 Frequency Setting Methods (Program I) for SCRFD Line 217

Line 217 in Los-Angeles has been selected to examine the computerized system. It is considered as a heavy line which carries a relatively large amount of passengers. Interesting to note is that this line includes ADCS equipment. However, the ride check data were collected manually and key-punched into SCRFD files. At present the absence of reliable data from the ADCS precluded any basis for recommending to use it. It is anticipated, however, that the recurring ADCS equipment problems will be resolved in the near future to open up the opportunity for further examination of the computerized systems developed.



Figure 12

THE GEOMETRY OF SCRTD LINE 217



The geometry of Line 217 is shown in Figure 12. This line is characterized by 60 stops and 9 timepoints. The timepoints are at the departure and arrival terminals and at the 14th, 23rd, 28th, 36th, 46th, 50th, and 51st stops. The line currently has 9 different short turns between stops 1-50, 1-28, 15-60, 15-50, 28,60, 28-50, 1-26, 15-26 and 26-46. However, most of its trips are initiating at the departure terminal and terminating at the arrival terminal. Moreover, all of the trips are crossing the daily max load point in which the alternative timetables are to be constructed.

The complete input to Program I of Line 217 (Northbound) appear in Appendix A. The basic input data which is arranged by Program I in a table form is displayed in Tables 14 (northbound) and 15 (southbound). 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 Tables 14 and 15 is a representative load for a given hour and stop. Usually it is expected that these entries will be based on average values across several checks. However, at present, SCRTD files are based only on one day of ride check data.

The intermediate results of Program I show that the daily max load point for the north direction is the Fairfax/Rosewood stop with a total of 4413 observed passengers through the whole day. For the south direction such a stop is the Fairfax/Beverly with 4543 observed passengers. These results are shown in Tables 16 and 17. Also, a computer generated load profiles are provided for each time period to allow the scheduler to visually observe the load variation among stops. Two examples for each travel direction are exhibited in Figure 13 and 14 (north) and 15 and 16 (south). Each asterisk in these figures represent five passengers. The area under scale is not sensi-

Table 14 INITIAL DATA FOR BUS NO. 217

DIRECTION: A (North)

NUMBER OF PASSENGERS PER INTERVAL

TIME INTERVAL	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	2500	TOTAL
NO OF BUSES	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	2500		
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
RECOMMENDED NO. OF PASS.	60	70	70	60	50	50	50	50	50	60	70	70	60	60	50	50	50	50	50	50	
DIST ST. NAME																					
0.18 ADAMS /WASHINGTON	13	27	115	24	11	11	6	4	10	9	16	23	18	8	2	3	2	5	1		308
0.28 FAIRFAX /ADAMS	21	88	148	39	16	27	26	8	16	19	24	38	23	12	3	7	2	5	1		503
0.27 FAIRFAX /WASHINGTON	22	89	160	48	22	32	29	15	23	20	35	40	23	15	3	8	6	5	1		596
0.26 FAIRFAX /APPLE	25	101	163	51	26	34	29	16	23	23	40	45	24	14	3	8	6	5	1		637
0.27 FAIRFAX /VENICE	29	112	183	53	37	43	37	22	26	34	60	51	32	19	3	8	9	5	2		765
0.27 FAIRFAX /VENICE F	37	124	217	84	52	44	51	38	36	48	78	60	37	21	7	8	10	6	3		961
0.24 FAIRFAX /18TH	40	119	188	83	51	45	52	39	57	57	78	61	37	20	6	8	9	6	3		939
0.24 FAIRFAX /AIRDROME	40	131	192	89	52	49	54	42	38	60	77	65	35	19	8	11	9	7	3		981
0.24 FAIRFAX /PICKFORD	45	151	195	94	48	50	54	42	40	60	78	67	35	19	9	12	9	7	3		1018
0.24 FAIRFAX /SATURN	48	167	211	97	58	50	55	45	39	60	73	63	31	18	9	13	9	7	3		1056
0.24 FAIRFAX /PICO	56	217	246	116	83	78	84	95	73	94	105	97	49	30	11	12	14	8	4		1472
0.26 FAIRFAX /PACKARD	59	228	252	120	91	80	87	98	76	98	105	98	47	30	11	12	15	8	4		1517
0.26 FAIRFAX /WHITWORT	63	250	257	125	98	87	90	100	78	98	104	98	53	31	14	12	15	9	4		1584
0.00 FAIRFAX /OLYMPIC	59	244	275	130	108	98	103	120	99	86	122	99	54	38	16	12	18	10	5		1696
0.24 OLYMPIC /ODDEN	59	332	278	152	123	99	116	142	103	104	129	115	64	39	16	12	18	10	5		1916
0.22 FAIRFAX /SAN VICE	70	355	325	171	144	124	141	181	142	149	151	134	73	40	17	15	19	12	6		2269
0.24 FAIRFAX /8TH ST.	66	357	330	175	150	128	145	188	164	156	170	158	77	42	18	16	19	13	6		2378
0.29 FAIRFAX /WILSHIRE	54	363	349	236	288	250	354	356	342	397	382	343	190	91	40	24	36	18	8		4121
0.29 FAIRFAX /8TH ST	55	369	351	238	291	257	363	365	347	398	386	343	189	94	41	27	34	18	8		4174
0.29 FAIRFAX /DREXEL	54	376	355	234	291	258	381	378	350	398	391	339	191	93	42	27	34	18	9		4219
0.29 FAIRFAX /3RD ST	48	401	370	234	261	258	338	381	367	412	454	367	205	101	56	37	38	19	9		4356
0.29 FAIRFAX /1ST ST.	48	400	366	232	265	256	339	385	373	422	440	368	206	104	54	37	39	19	9		4362
0.34 FAIRFAX /BEVERLY	44	392	354	232	249	252	314	362	353	409	459	377	218	98	59	44	44	20	9		4289
0.35 FAIRFAX /OAKWOOD	52	391	351	237	271	282	315	366	352	416	467	370	220	106	57	46	51	22	9		4383
0.34 FAIRFAX /ROSEWOOD	49	370	326	246	288	292	327	376	367	418	481	371	214	102	57	50	51	20	8		4413
0.35 FAIRFAX /MELROSE	46	113	175	165	245	265	308	378	365	427	439	370	201	101	51	47	50	20	8		3774
0.34 FAIRFAX /WILLOWGH	44	112	173	155	238	246	291	358	344	406	411	353	191	91	51	45	48	19	8		3584
0.35 FAIRFAX /SANTA MO	33	90	140	148	154	174	216	292	273	322	353	299	171	97	45	50	51	19	4		2931
0.35 FAIRFAX /FOUNTAIN	35	92	134	153	149	172	208	281	244	300	321	283	157	89	42	49	49	20	4		2782
0.29 FAIRFAX /SUNSET	32	70	95	132	127	144	172	249	210	270	280	264	144	80	44	48	48	20	4		2433
0.29 SUNSET /GENESEE	31	69	90	133	125	143	170	248	206	269	287	259	146	80	42	46	47	20	4		2417
0.29 SUNSET /STANLEY	30	71	92	135	127	135	171	248	206	260	288	253	145	77	43	46	48	18	4		2397
0.29 SUNSET /GARDNER	31	73	85	132	117	124	165	240	210	249	274	241	138	83	43	46	45	17	4		2317
0.29 SUNSET /MARTEL	32	75	82	131	110	116	164	228	208	236	263	228	128	82	40	47	45	17	4		2236
0.29 SUNSET /POINSETT	33	73	77	127	118	115	171	220	193	232	260	222	129	81	38	55	46	18	4		2212
0.30 LA BREA /SUNSET	36	65	70	122	113	106	163	211	177	222	252	218	132	86	39	54	45	17	2		2130
0.18 LA BREA /HOLLYWOOD	36	62	68	118	116	98	156	199	172	213	242	206	127	81	36	56	42	16	1		2045
0.18 HOLLYWOOD /SYCAMORE	36	65	67	118	116	104	155	192	165	208	225	194	122	78	38	56	45	17	1		2002
0.18 HOLLYWOOD /ORANGE	32	62	66	112	112	107	152	176	166	197	204	179	113	75	36	54	43	17	1		1904
0.18 HOLLYWOOD /HIGHLAND	19	33	49	84	90	94	130	147	154	185	146	146	88	65	33	55	35	16	2		1571
0.18 HOLLYWOOD /LAS PALM	16	26	45	77	83	89	120	126	140	168	141	139	85	58	31	55	34	15	2		1450
0.18 HOLLYWOOD /WHITLEY	15	22	42	62	67	76	111	92	116	144	129	116	68	43	27	53	31	13	2		1229
0.18 HOLLYWOOD /WILCOX	14	21	40	54	62	66	105	84	108	131	119	98	58	38	18	44	27	13	2		1102
0.19 HOLLYWOOD /CAMUENGA	11	20	36	44	61	66	90	80	96	123	107	85	50	40	16	41	25	13	1		1005
0.19 HOLLYWOOD /IVAR	9	16	33	33	50	57	73	61	84	111	98	84	47	35	14	29	24	10	1		869
0.19 HOLLYWOOD /VINE	3	14	19	17	31	39	35	33	68	87	73	67	47	25	14	24	17	9	1		623
0.19 ARGYLE /HOLLYWOOD	4	20	17	20	31	35	32	44	69	91	83	66	47	20	16	24	15	10	0		644
0.19 ARGYLE /YUCCA	3	20	17	19	30	28	32	44	68	81	79	64	44	15	13	21	11	9	0		598
0.27 FRANKLIN /ARGYLE	2	16	17	16	21	22	29	34	47	64	59	47	25	11	10	17	8	6	0		451
0.11 GOWER /FRANKLIN	2	8	13	11	10	16	21	21	27	53	38	30	10	8	6	6	0	0	0		282
0.16 BEACHWOOD /FRANKLIN	2	11	11	12	8	9	15	12	25	49	21	24	7	4	6	3	0	0	0		219
0.18 BEACHWOOD /MIDWAY	2	11	11	11	8	6	14	12	25	48	19	19	5	2	5	3	0	0	0		201
0.18 BEACHWOOD /SCENIC	2	10	11	10	7	5	13	11	16	44	17	18	4	2	5	3	0	0	0		178
0.16 BEACHWOOD /TEMPLE H	2	9	10	9	7	4	10	9	14	44	14	13	3	2	3	3	0	0	0		156
0.18 BEACHWOOD /WINANS	1	7	10	9	7	4	5	6	13	39	13	12	1	1	3	3	0	0	0		134
0.18 BEACHWOOD /CHEREMOV	1	7	9	6	7	3	5	4	10	34	11	7	1	1	3	3	0	0	0		112
0.18 BEACHWOOD /GLEN ALD	1	7	7	6	6	3	4	4	8	30	10	5	1	1	2	1	0	0	0		96
0.19 BEACHWOOD /GLEN DAK	1	7	7	6	6	3	2	4	8	26	8	4	1	1	2	1	0	0	0		87
0.21 BEACHWOOD /WESTSHIR	0	7	6	6	2	3	2	3	0	5	5	2									

Table 15 INITIAL DATA FOR BUS NO. 217

DIRECTION: B (South)

NUMBER OF PASSENGERS PER INTERVAL

TIME INTERVAL	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	2500	TOTAL
NO OF BUSES	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	2500		
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
RECOMMENDED NO. OF PASS.	60	70	70	60	50	50	50	50	50	60	70	70	60	60	50	50	50	50	50	50	
DIST ST. NAME																					
0.40 BEACHWOOD/WESTSHIR	1	6	6	3	4	3	5	3	5	7	6	5	3	2	2	1	3	0	0	0	65
0.22 BEACHWOOD/GLEN OAK	2	6	6	4	7	3	7	3	6	8	6	4	4	3	4	2	3	0	0	0	78
0.22 BEACHWOOD/GLEN ALD	2	7	8	7	9	3	9	3	7	8	6	4	5	4	4	2	3	0	0	0	91
0.22 BEACHWOOD/GOWER	7	12	8	7	9	4	10	5	7	8	8	5	5	4	4	2	3	0	0	0	108
0.22 BEACHWOOD/WINANS	7	17	8	8	10	5	12	6	9	11	8	5	5	4	4	2	3	0	0	0	124
0.22 BEACHWOOD/TEMPL HI	8	20	12	12	13	6	12	9	11	11	11	8	6	4	4	2	3	0	0	0	152
0.16 BEACHWOOD/SCENIC	10	27	16	17	15	5	15	12	11	11	12	7	6	5	4	2	3	0	0	0	178
0.18 BEACHWOOD/MIDWAY	10	33	20	18	15	7	16	13	11	13	12	7	6	7	4	2	3	0	0	0	197
0.16 FRANKLIN/BEACHWOOD	12	37	31	22	27	12	17	18	14	16	17	6	7	6	4	3	3	0	0	0	252
0.18 FRANKLIN/VISTA D	15	41	41	25	34	12	19	18	17	16	17	7	7	6	4	4	3	0	0	0	286
0.00 ARGYLE /YUCCA	14	43	42	25	35	14	20	18	17	16	17	7	7	7	6	4	3	0	0	0	295
0.42 GOWER /FRANKLIN	20	47	57	41	43	25	33	25	22	23	26	15	14	8	8	5	4	1	0	0	417
0.13 ARGYLE /HOLLYWOOD	19	52	67	44	44	25	35	26	22	25	27	17	13	9	9	5	4	1	0	0	444
0.13 HOLLYWOOD/VINE	27	56	66	56	69	66	69	53	60	48	64	44	22	13	19	11	6	1	5	5	755
0.14 HOLLYWOOD/IVAR	30	60	77	68	82	86	88	68	76	65	72	56	31	19	19	14	6	7	6	9	930
0.21 HOLLYWOOD/CAHUENGA	34	69	86	75	91	94	100	83	86	73	84	62	40	21	21	14	6	8	6	6	1053
0.21 HOLLYWOOD/WILCOX	46	86	98	86	101	108	115	95	103	84	101	69	43	29	27	15	6	11	6	12	1227
0.21 HOLLYWOOD/WHITLEY	49	100	113	105	123	128	131	110	116	112	118	92	50	39	34	16	9	15	11	11	1471
0.21 HOLLYWOOD/LAS PALM	51	112	129	113	128	131	138	112	123	124	132	99	55	51	36	16	12	15	11	15	1588
0.21 HOLLYWOOD/HIGHLAND	66	138	171	142	165	154	156	146	174	167	178	129	92	63	54	28	16	26	11	20	2076
0.21 HOLLYWOOD/ORANGE	68	141	177	153	168	154	155	149	174	176	185	143	86	63	53	27	22	30	11	21	2135
0.22 HOLLYWOOD/SYCAMORE	69	145	183	154	173	150	155	151	182	178	183	147	88	66	55	31	22	29	11	21	2172
0.29 LA BREA /HOLLYWOOD	71	149	186	159	174	166	162	157	179	189	190	142	87	63	53	29	22	27	11	22	2216
0.29 LA BREA /SUNSET	69	161	208	163	182	166	164	159	185	196	194	146	89	58	54	32	22	29	13	22	2290
0.29 SUNSET /POINSETT	71	172	216	169	194	183	171	173	182	200	185	130	92	58	51	32	22	27	12	23	2338
0.29 SUNSET /MARTEL	73	185	226	185	200	186	188	179	187	206	180	127	97	56	50	35	22	30	12	24	2424
0.29 SUNSET /GARDNER	77	197	232	194	210	189	200	177	187	210	171	128	94	55	48	36	24	31	13	24	2473
0.29 SUNSET /STANLEY	77	201	244	195	216	185	200	177	181	213	165	128	92	53	48	37	24	31	13	24	2480
0.30 SUNSET /GENESEE	78	206	246	194	214	184	200	179	182	212	167	126	91	50	47	37	24	31	13	24	2481
0.42 FAIRFAX /SUNSET	82	231	260	208	229	211	222	202	192	243	187	155	101	49	46	42	22	31	9	27	2722
0.32 FAIRFAX /FOUNTAIN	96	261	277	247	247	226	229	206	202	247	193	153	95	50	41	43	24	31	10	28	2878
0.34 FAIRFAX /STA MONI	123	336	361	372	338	298	245	279	243	326	229	154	100	65	39	42	23	31	13	36	3617
0.34 FAIRFAX /WILLOUGH	135	371	395	413	352	313	264	300	266	340	224	150	101	64	39	43	21	29	13	38	3833
0.34 FAIRFAX /MELROSE	140	335	410	416	387	352	306	408	465	548	236	167	112	68	37	43	22	27	13	44	4492
0.34 FAIRFAX /ROSEWOOD	137	348	402	367	371	326	310	370	471	540	234	171	130	64	37	40	18	25	13	43	4374
0.34 FAIRFAX /DAKWOOD	139	354	401	386	386	327	318	393	488	555	234	173	134	70	36	40	19	23	13	44	4489
0.27 FAIRFAX /BEVERLY	144	330	394	400	392	334	340	378	485	565	271	189	128	64	37	38	19	23	14	45	4543
0.29 FAIRFAX /1ST ST	147	333	385	405	392	334	333	366	493	555	266	192	130	62	37	35	21	23	14	45	4523
0.29 FAIRFAX /3RD ST	147	325	334	344	314	277	273	342	462	486	267	197	134	64	36	32	20	22	14	40	4090
0.27 FAIRFAX /DREXEL	146	326	333	324	297	279	274	339	473	485	278	189	137	62	36	32	20	22	14	40	4066
0.29 FAIRFAX /6TH ST	145	324	326	315	291	269	266	332	469	480	276	181	132	60	35	30	20	20	14	39	3985
0.29 FAIRFAX /WILSHIRE	73	151	141	114	134	132	167	171	321	367	229	161	128	41	31	32	13	15	10	24	2431
0.29 FAIRFAX /DEL VALL	75	150	137	110	122	132	165	169	318	368	222	159	126	37	29	32	13	15	10	23	2389
0.05 FAIRFAX /SAN VICE	63	121	112	75	92	104	142	120	253	305	183	145	116	37	29	31	13	13	10	19	1964
0.19 OLYMPIC /OGDEN	57	120	108	72	75	97	134	111	233	274	178	120	104	37	29	31	13	13	10	18	1816
0.21 FAIRFAX /OLYMPIC	60	121	90	65	68	77	109	100	178	231	170	108	96	28	27	30	12	13	9	15	1592
0.19 FAIRFAX /WHITWORT	60	133	89	65	65	75	103	98	178	219	158	102	94	27	26	29	12	12	8	15	1551
0.21 FAIRFAX /PACKARD	60	135	88	63	64	78	93	95	170	214	153	89	90	26	19	29	11	11	8	14	1492
0.24 FAIRFAX /PICO	43	80	46	38	33	57	66	69	112	162	125	76	79	17	14	30	8	11	9	10	1075
0.24 FAIRFAX /SATURN	45	82	42	36	31	51	65	60	109	160	119	71	71	17	14	29	8	11	8	10	1029
0.24 FAIRFAX /PICKFORD	46	82	38	32	35	51	65	55	106	148	116	68	70	17	12	29	7	10	7	9	994
0.24 FAIRFAX /AIRDROME	47	81	31	32	35	50	63	52	98	144	104	59	58	14	12	29	7	10	7	9	933
0.22 FAIRFAX /18TH	47	68	31	32	35	52	59	43	116	141	93	59	58	13	12	29	7	9	7	9	911
0.22 FAIRFAX /SAWYER	47	68	31	32	35	52	59	43	116	141	89	59	58	13	12	29	7	9	7	9	907
0.22 FAIRFAX /VENICE	40	44	19	19	30	41	40	29	93	116	63	42	46	10	6	21	2	8	4	6	673
0.22 FAIRFAX /VENICE F	38	44	19	18	31	41	30	28	94	106	58	34	38	10	6	21	2	8	3	6	629
0.22 FAIRFAX /ST MNC F	38	43	16	17	30	40	29	26	84	95	51	32	34	8	5	21	2	8	3	5	582
0.22 WASHINGT /DAVID	33	40	15	16	26	34	24	24	75	82	47	25	25								

Table 16 Max Load Information-North Direction

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

Table 17 Max Load Information-South Direction

MAXIMUM LOAD POINT BY METHOD 1 IS FAIRFAX /BEVERLY --- 4543 PASSENGERS FOR DAY

INTERMEDIATE RESULTS FOR METHOD 2

TIME INTERVAL	MAXIMUM LOAD POINT	NO. OF PASSENGERS
0600 0700	FAIRFAX /1ST ST FAIRFAX /3RD ST	147
0700 0800	FAIRFAX /WILLOUGH	371
0800 0900	FAIRFAX /MELROSE	410
0900 1000	FAIRFAX /MELROSE	416
1000 1100	FAIRFAX /BEVERLY FAIRFAX /1ST ST	392
1100 1200	FAIRFAX /MELROSE	352
1200 1300	FAIRFAX /BEVERLY	340
1300 1400	FAIRFAX /MELROSE	408
1400 1500	FAIRFAX /1ST ST	493
1500 1600	FAIRFAX /BEVERLY	565
1600 1700	FAIRFAX /DREXEL	278
1700 1800	FAIRFAX /3RD ST	197
1800 1900	FAIRFAX /DREXEL	137
1900 2000	FAIRFAX /DAKWOOD	70
2000 2100	HOLLYWOOD/SYCAMORE	55
2100 2200	FAIRFAX /FOUNTAIN FAIRFAX /WILLOUGH FAIRFAX /MELROSE	43
2200 2300	SUNSET /GARDNER SUNSET /STANLEY SUNSET /GENESEE FAIRFAX /FOUNTAIN	24
2300 2400	SUNSET /GARDNER SUNSET /STANLEY SUNSET /GENESEE FAIRFAX /SUNSET FAIRFAX /FOUNTAIN FAIRFAX /STA MONI	31
2400 2500	FAIRFAX /BEVERLY FAIRFAX /1ST ST FAIRFAX /3RD ST FAIRFAX /DREXEL FAIRFAX /6TH ST	14

Figure 13 Morning-peak Load Profile for Line 217  
(North Direction)

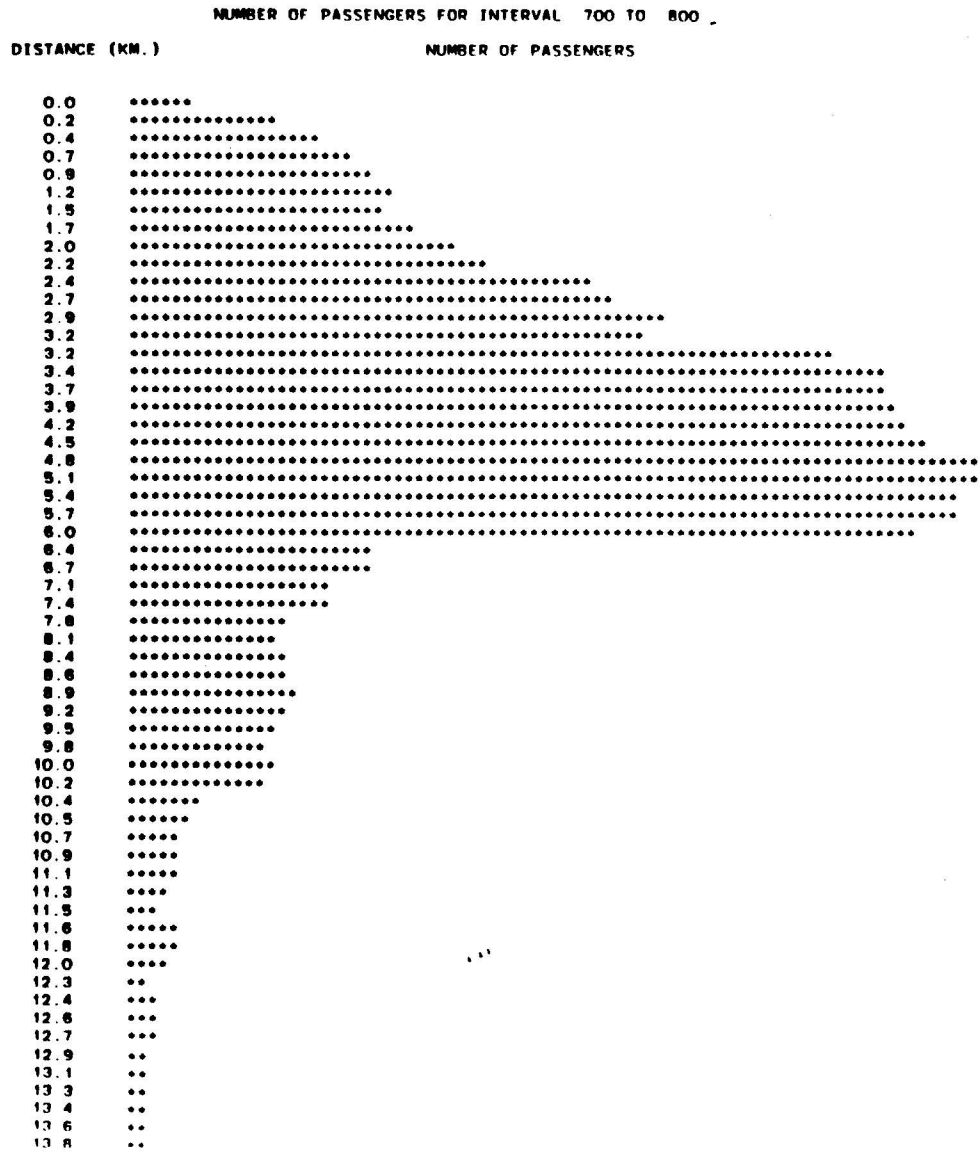


Figure 14 Afternoon-peak Load Profile for Line 217  
(North Direction)

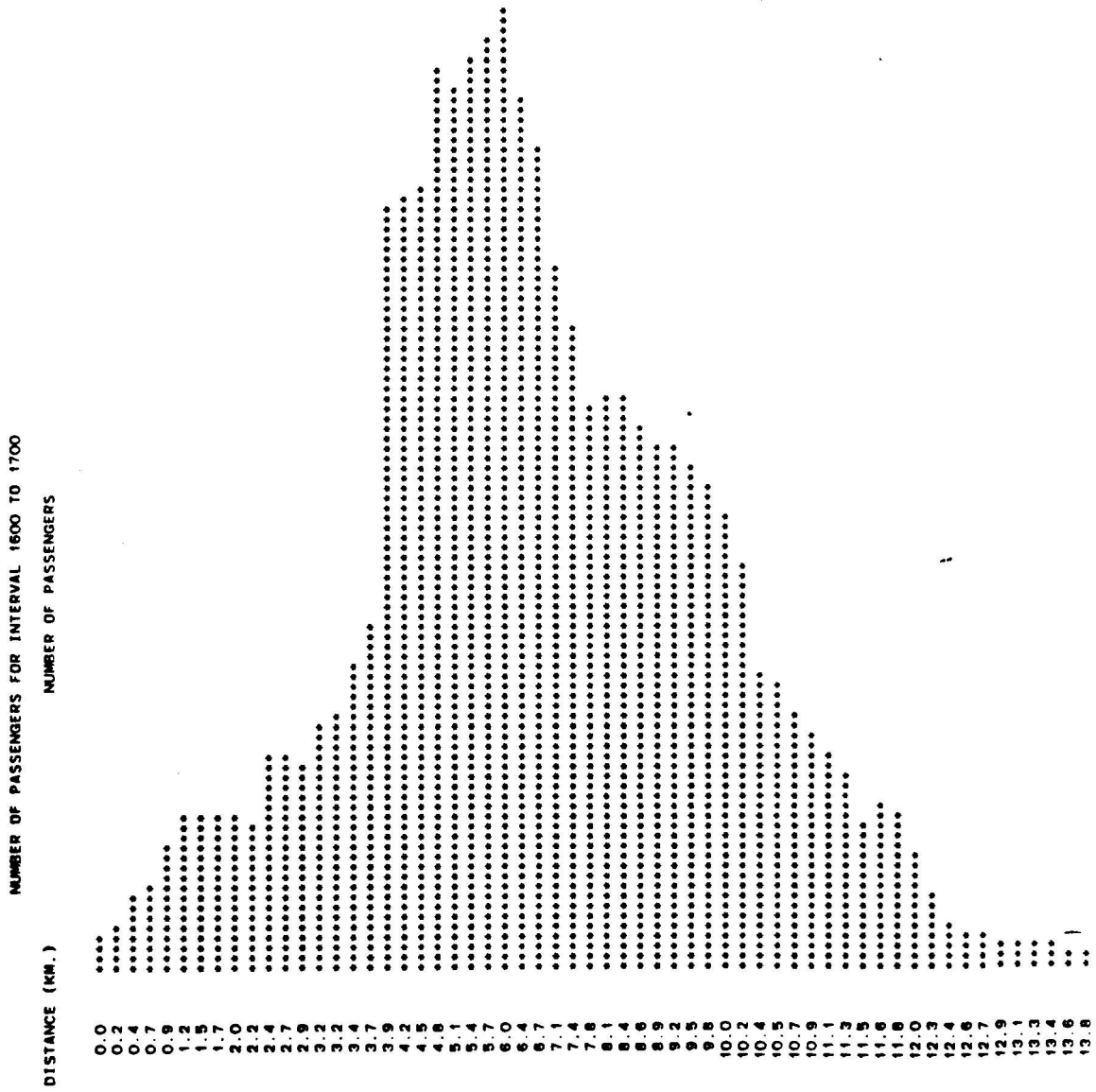
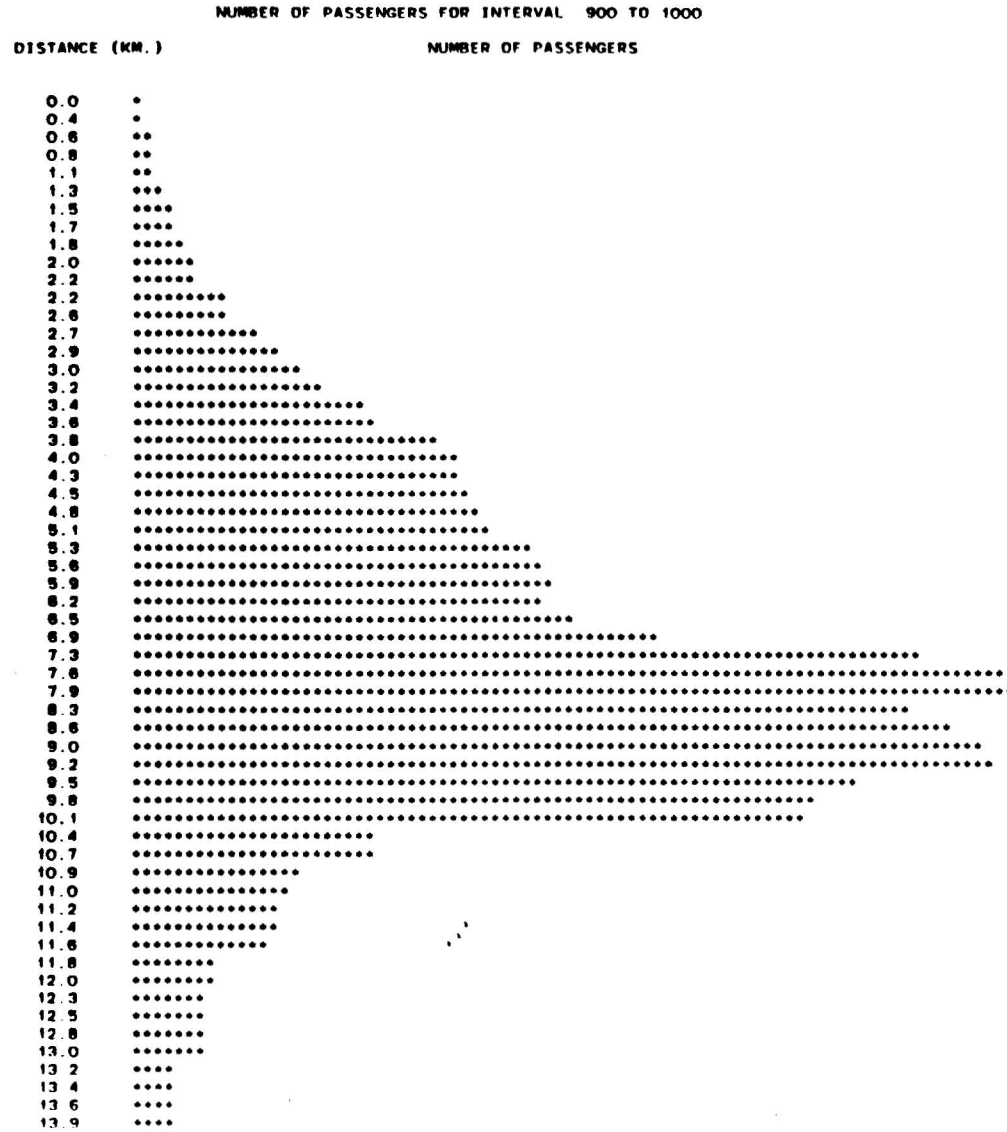


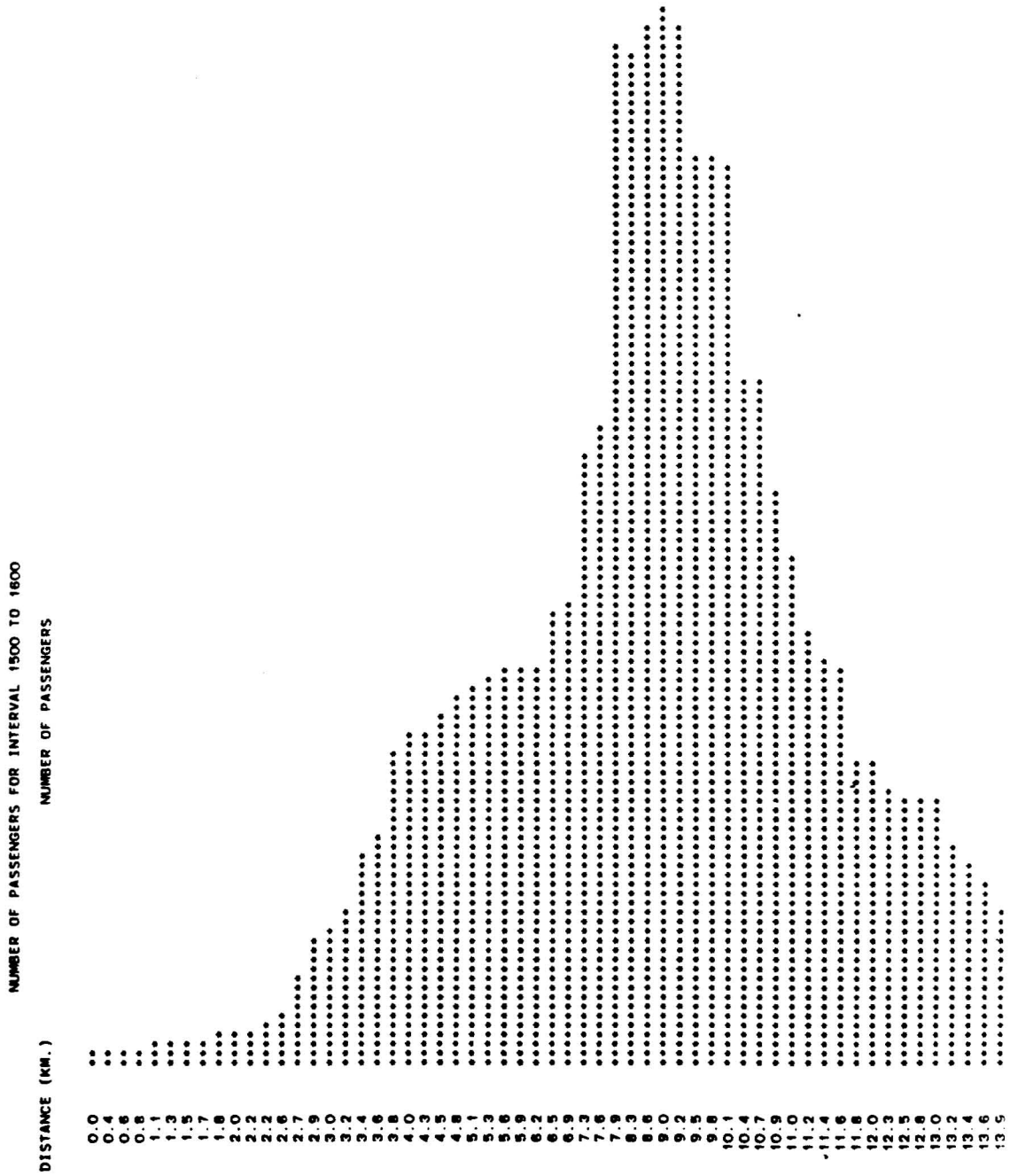


Figure 15 Morning-peak Load Profile for Line 217  
(South Direction)



-75-

Figure 16 Afternoon-peak Load Profile for Line 217  
(South Direction)



tive to distances less than 0.5 km for this visual display, and therefore it seems that the stops are evenly spaced along the entire route. Figures 13 and 15 display the morning peak profile while Figures 14 and 16 -- the afternoon peak profile for the north and south directions, respectively. The output of Program I includes a measure of density for each load profile: the area under the profile curve divided by the max observed load times the route length. This density measure is 35.8%, 41.9%, 36.3% and 38.5% for Figures 13, 14, 15 and 16, respectively. Low densities mean low productivity (relatively high empty seat-kilometers) and may advise to consider short turns.

The frequency and headway results of Program I are shown in Tables 18 (northbound) and 19 (southbound). The statistical (chi-square) comparison between the results of Method 1 and Method 2 reveals that at the 95% significant level the null hypothesis about equal methods is rejected. Consequently, for a point check method it is recommended to gather the data at the hourly max load points. The results of Method 4 in Tables 18 and 19 are shown for three different constraint levels: 10%, 20% and 30% of the route length (of 13.9 km) is allowed to have an observed load exceeding the desired occupancy. In the remainder parts of this chapter Method 4 is associated with the 20% constraint. Bus capacity for Method 3 and 4 is considered as 80 passengers (see equations (3) and (4) in Chapter 2).

The graphical comparison between the frequency results of three methods and the observed frequency is exhibited in Figure 17 for both directions of Line 217. It can be easily seen that the provided frequencies in both directions represents excessive amount of bus runs. The desired occupancy for each time period appears in Tables 14 and 15 in the fourth row and was set forth by SCRTD schedulers. Using these load factors and either Method 2 or Method 4 can result in significant resource saving. It is interesting to note that Method 4 results in much lower frequency than Method 2 particularly in the south direction. The absolute minimum frequency to accommodate the

FIGURE 17

Graphic comparison between the observed and the derived frequencies.

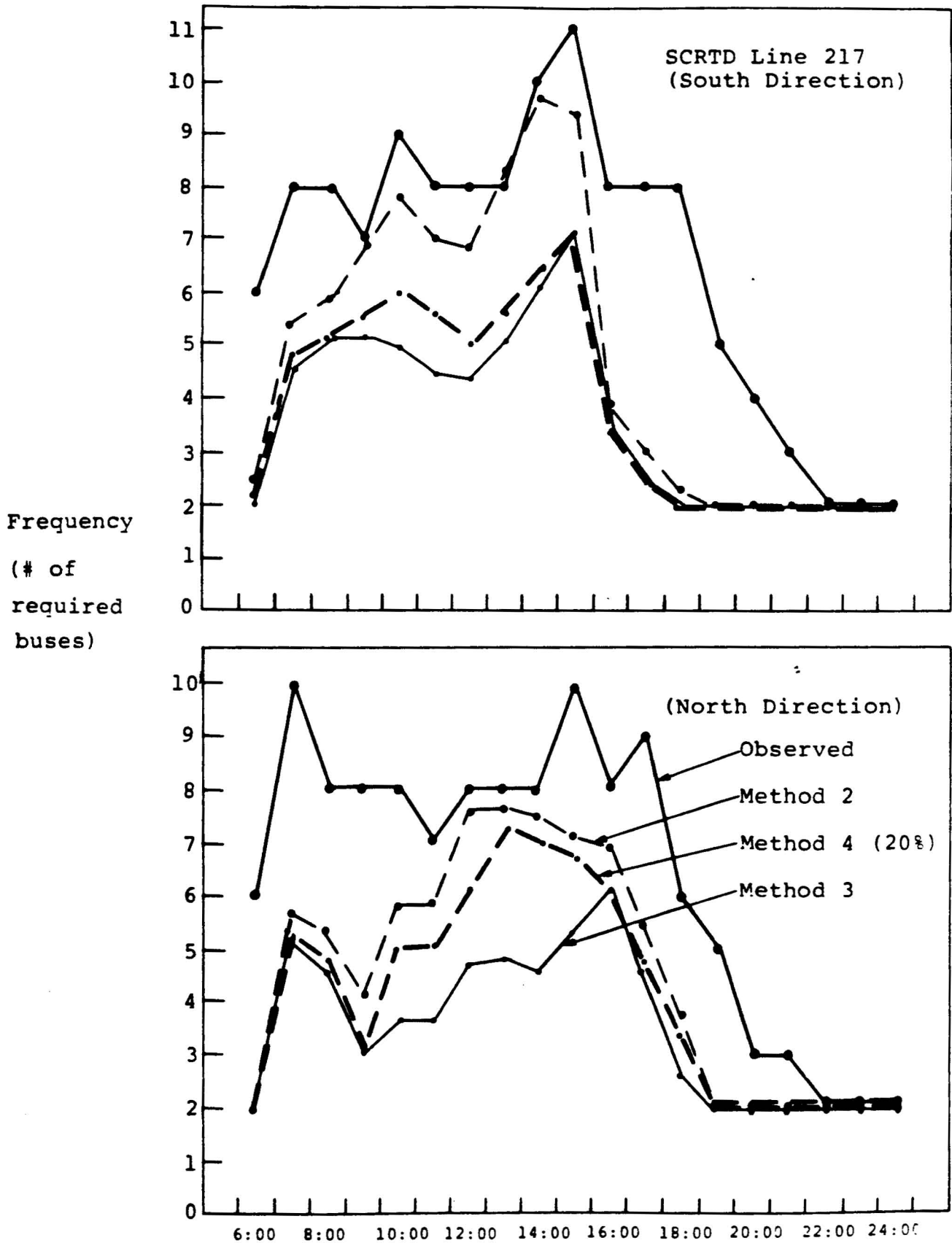


Table 18 Frequency and Headway Results

RESULTS OF FOUR METHODS

BUS NUMBER 217 DIRECTION A (North)

TIME INTERVAL	METHOD 1		METHOD 2		METHOD 3		METHOD 4					
	NO. OF BUSES	HEADWAY	NO. OF BUSES	HEADWAY	NO. OF BUSES	HEADWAY	BY 10%		BY 20%		BY 30%	
							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.



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passenger load while neglecting the load factors is presented by Method 3 and in most hours is as half as the presently provided frequency. Further interpretation of these results is described in the next section.

### 6.3 Alternative Timetables (Program II) for SCRTD Line 217

The PL/1 Program II which is based on the procedures developed in Chapter 3, 4 and 5, is used for the SCRTD Line 217 to construct alternative timetables. The complete input to this program appears in Appendix B for both the north and south directions. The first row in this input represents three entries: total number of time periods (19), number of frequency setting methods to be used (4) and total number of observed departures at the daily max load point (135 for the north and 141 for the south direction). The next 19 rows in this input refer to each time period. In these rows the fifth column is the round trip time including layover and turn around times, and the last four columns are the frequency results of the four methods. The remaining rows present the data for each individual departure. In these rows the fourth column is the observed departure times at the Fairfax/Rosewood and Fairfax/Beverly stops for the north and south directions, respectively. In this column the end of each time period is shown if it does not coincide with a departure time. The fifth column is the difference between the third and fourth columns (headways in minutes), and the last four columns refer to the four methods. That is, the load at the daily max load point, the load at the hourly max load point and the area of the load profile, respectively.

Sixteen different combinations of runs have been selected for each direction of travel. These combinations are shown in Table 20 and are accompanied with the results of the comparison measures for each run. Tables 21 to 25 display five different computer generated timetables at the Fairfax/Rosewood stop (northbound), and Tables 26 to 30 display similar timetables at the Fairfax/Beverly stop (south bound). The remaining 22 time-



Table 20

DESCRIPTION OF THE 16 COMBINATIONS OF REQUESTS TO RUN PROGRAM II ACCOMPANIED WITH THE RESULTS OF THE COMPARISON MEASURES

Run Number	Direction of Travel S = South N = North	Type of Headway 1 = equal 2 = Balanced	Number of Combinations To Be Used	Method Number	Clock Headway 1 = With 0 = Without	Specified Number of Departures 0 = Not Specified	Results of Comparison Measures	
							Number of Departures	Minimum Fleet Size
1	N	1	1	1	0	0	84	15
2	N	1	1	2	0	0	87	15
3	N	1	1	3	0	0	67	11
4	N	1	1	4	0	0	78	14
5	N	1	5	2,4*	0	0	85	15
6	N	1	1	2	1	0	80	16
7	N	1	1	4	1	0	78	14
8	N	1	1	2	0	70	70	12
9	N	1	1	2	0	140	140	24
10	N	2	1	1	0	0	84	15
11	N	2	1	2	0	0	87	15
12	N	2	1	3	0	0	67	11
13	N	2	1	4	0	0	78	14
14	N	2	5	2,4*	0	0	85	15
15	N	2	1	2	0	70	70	12
16	N	2	1	2	0	140	140	24
17	S	1	1	1	0	0	88	19
18	S	1	1	2	0	0	91	19
19	S	1	1	3	0	0	69	13
20	S	1	1	4	0	0	73	13
21	S	1	5	2,4*	0	0	89	19
22	S	1	1	2	1	0	91	20
23	S	1	1	4	1	0	74	14
24	S	1	1	2	0	70	70	15
25	S	1	1	2	0	140	140	30
26	S	2	1	1	0	0	88	19
27	S	2	1	2	0	0	91	20
28	S	2	1	3	0	0	69	13
29	S	2	1	4	0	0	73	13
30	S	2	5	2,4*	0	0	89	20
31	S	2	1	2	0	70	70	15
32	S	2	1	2	0	140	140	30

\* Method 2 is used for off-peak periods #(1), (4,5,6,7,8,9,10,11), (14,15,16,17,18,19); Method 4 is used for peak periods #(2,3), (12,13) — total of 5 combinations.

Table 21 Computer Generated Timetable of Line 217  
at the Fairfax/Rosewood Stop

TYPE OF HEADWAYS : EQUAL (1)

TIMETABLE

TYPE OF TIMETABLE: ONE METHOD (1)

\*\*\*\*\*

METHOD NUMBER: 2 FROM INTERVAL: 1 TO INTERVAL: 19

CLOCK HEADWAYS: NO (0)

		DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME
MAX	4				
MAX	6	1	6.00	44	13.54
MAX	9	2	6.30	45	14.02
MAX	9	3	7.00	46	14.10
MAX	9	4	7.11	47	14.18
MAX	9	5	7.21	48	14.26
MAX	9	6	7.32	49	14.34
MAX	9	7	7.42	50	14.42
MAX	9	8	7.53	51	14.50
MAX	9	9	8.04	52	14.58
MAX	9	10	8.15	53	15.07
MAX	9	11	8.27	54	15.15
MAX	9	12	8.38	55	15.24
MAX	9	13	8.49	56	15.32
MAX	9	14	9.01	57	15.41
MAX	9	15	9.16	58	15.49
MAX	9	16	9.31	59	15.58
MAX	11	17	9.45	60	16.06
MAX	11	18	10.00	61	16.15
MAX	11	19	10.10	62	16.24
MAX	11	20	10.21	63	16.33
MAX	12	21	10.31	64	16.42
MAX	12	22	10.42	65	16.50
MAX	12	23	10.52	66	16.59
MAX	13	24	11.02	67	17.10
MAX	13	25	11.13	68	17.21
MAX	13	26	11.23	69	17.33
MAX	14	27	11.33	70	17.44
MAX	14	28	11.44	71	17.55
MAX	14	29	11.54	72	18.09
MAX	14	30	12.03	73	18.26
MAX	14	31	12.11	74	18.42
MAX	14	32	12.19	75	18.59
MAX	14	33	12.27	76	19.28
MAX	14	34	12.35	77	19.58
MAX	14	35	12.43	78	20.28
MAX	14	36	12.51	79	20.58
MAX	15	37	12.59	80	21.29
MAX	15	38	13.07	81	21.59
MAX	15	39	13.15	82	22.29
MAX	15	40	13.22	83	22.59
MAX	15	41	13.30	84	23.29
MAX	15	42	13.38	85	24.00
MAX	15	43	13.46	86	0.30
MAX	15			87	1.00
MAX	15				
MAX	15				
MAX	15				
MAX	15				
MAX	15				

COMPARISON MEASURES

\*\*\*\*\*

TOTAL NUMBER OF DEPARTURES: 87  
MINIMUM SINGLE ROUTE (ROUND TRIP) REQUIRED FLEET SIZE

Table 22 Computer Generated Timetable of Line 217  
at the Fairfax/Rosewood Stop

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

\*\*\*\*\*

DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME
1	6.00	40	14.11
2	6.30	41	14.20
3	7.00	42	14.29
4	7.12	43	14.38
5	7.24	44	14.46
6	7.36	45	14.55
7	7.48	46	15.04
8	8.00	47	15.13
9	8.13	48	15.22
10	8.26	49	15.31
11	8.39	50	15.40
12	8.51	51	15.49
13	9.07	52	15.58
14	9.26	53	16.08
15	9.46	54	16.18
16	10.04	55	16.28
17	10.16	56	16.38
18	10.28	57	16.49
19	10.41	58	16.59
20	10.53	59	17.11
21	11.05	60	17.23
22	11.17	61	17.36
23	11.30	62	17.48
24	11.42	63	18.01
25	11.54	64	18.19
26	12.05	65	18.38
27	12.15	66	18.57
28	12.25	67	19.25
29	12.34	68	19.56
30	12.44	69	20.26
31	12.54	70	20.57
32	13.03	71	21.27
33	13.12	72	21.57
34	13.20	73	22.28
35	13.29	74	22.58
36	13.37	75	23.29
37	13.46	76	23.59
38	13.54	77	0.30
39	14.03	78	1.00

COMPARISON MEASURES

\*\*\*\*\*

TOTAL NUMBER OF DEPARTURES: 78

MINIMUM SINGLE ROUTE (ROUND TRIP) REQUIRED FLEET SIZE 14

Table 23 Computer Generated Timetable of Line 217  
at the Fairfax/Rosewood Stop

TYPE OF HEADWAYS :EQUAL (1)

TYPE OF TIMETABLE:ONE METHOD (1)

METHOD NUMBER: 2 FROM INTERVAL: 1 TO INTERVAL: 19

CLOCK HEADWAYS :YES (1)

TIMETABLE

\*\*\*\*\*

DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME
1	6.00	45	13.52
2	6.30	46	14.00
3	7.00	47	14.07
4	7.10	48	14.15
5	7.20	49	14.22
6	7.30	50	14.30
7	7.40	51	14.37
8	7.50	52	14.45
9	8.00	53	14.52
10	8.12	54	15.00
11	8.24	55	15.07
12	8.36	56	15.15
13	8.48	57	15.22
14	9.00	58	15.30
15	9.15	59	15.37
16	9.30	60	15.45
17	9.45	61	15.52
18	10.00	62	16.00
19	10.10	63	16.10
20	10.20	64	16.20
21	10.30	65	16.30
22	10.40	66	16.40
23	10.50	67	16.50
24	11.00	68	17.00
25	11.10	69	17.12
26	11.20	70	17.24
27	11.30	71	17.36
28	11.40	72	17.48
29	11.50	73	18.00
30	12.00	74	18.15
31	12.07	75	18.30
32	12.15	76	18.45
33	12.22	77	19.00
34	12.30	78	19.30
35	12.37	79	20.00
36	12.45	80	20.30
37	12.52	81	21.00
38	13.00	82	21.30
39	13.07	83	22.00
40	13.15	84	22.30
41	13.22	85	23.00
42	13.30	86	23.30
43	13.37	87	24.00
44	13.45	88	0.30
		89	1.00

COMPARISON MEASURES  
\*\*\*\*\*

TOTAL NUMBER OF DEPARTURES: 89

MINIMUM SINGLE ROUTE (ROUND TRIP) REQUIRED FLEET SIZE 16

Table 24 Computer Generated Timetable of Line 217  
at the Fairfax/Rosewood Stop

TYPE OF HEADWAYS : BALANCED (2)

TYPE OF TIMETABLE: ONE METHOD (1)

METHOD NUMBER: 2 FROM INTERVAL: 1 TO INTERVAL: 19

CLOCK HEADWAYS: NO (0)

TIMETABLE

\*\*\*\*\*

DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME
1	6.00	44	13.53
2	6.38	45	14.02
3	7.03	46	14.08
4	7.23	47	14.15
5	7.35	48	14.29
6	7.42	49	14.35
7	7.50	50	14.44
8	7.56	51	14.53
9	8.02	52	14.59
10	8.10	53	15.08
11	8.21	54	15.16
12	8.36	55	15.23
13	8.44	56	15.34
14	9.01	57	15.40
15	9.11	58	15.48
16	9.25	59	15.58
17	9.39	60	16.05
18	10.00	61	16.14
19	10.12	62	16.26
20	10.24	63	16.33
21	10.35	64	16.43
22	10.44	65	16.49
23	10.54	66	16.59
24	11.04	67	17.09
25	11.13	68	17.19
26	11.20	69	17.27
27	11.32	70	17.46
28	11.43	71	17.56
29	11.54	72	18.12
30	12.03	73	18.25
31	12.07	74	18.41
32	12.14	75	18.57
33	12.25	76	19.28
34	12.33	77	19.58
35	12.40	78	20.23
36	12.49	79	20.59
37	12.58	80	21.34
38	13.05	81	21.58
39	13.10	82	22.26
40	13.17	83	22.59
41	13.25	84	23.17
42	13.34	85	23.59
43	13.44	86	0.13
		87	1.00

COMPARISON MEASURES

\*\*\*\*\*

TOTAL NUMBER OF DEPARTURES: 87  
MINIMUM SINGLE ROUTE (ROUND TRIP) REQUIRED FLEET SIZE 15

Table 25 Computer Generated Timetable of Line 217  
at the Fairfax/Rosewood Stop

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

\*\*\*\*\*

DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME
1	6.00	40	14.08
2	6.36	41	14.16
3	7.03	42	14.30
4	7.21	43	14.37
5	7.35	44	14.48
6	7.44	45	14.55
7	7.52	46	15.04
8	8.00	47	15.15
9	8.07	48	15.20
10	8.17	49	15.31
11	8.33	50	15.37
12	8.44	51	15.46
13	9.03	52	15.58
14	9.20	53	16.07
15	9.37	54	16.20
16	10.03	55	16.30
17	10.17	56	16.42
18	10.31	57	16.49
19	10.41	58	16.59
20	10.54	59	17.10
21	11.06	60	17.20
22	11.16	61	17.32
23	11.30	62	17.51
24	11.39	63	18.02
25	11.53	64	18.17
26	12.04	65	18.36
27	12.12	66	18.55
28	12.24	67	19.26
29	12.34	68	19.56
30	12.41	69	20.19
31	12.51	70	20.57
32	13.03	71	21.26
33	13.07	72	21.57
34	13.15	73	22.26
35	13.24	74	22.58
36	13.33	75	23.16
37	13.46	76	23.59
38	13.54	77	0.12
39	14.02	78	1.00

COMPARISON MEASURES

\*\*\*\*\*

TOTAL NUMBER OF DEPARTURES: 78  
MINIMUM SINGLE ROUTE (ROUND TRIP) REQUIRED FLEET SIZE 14

Table 26 Computer Generated Timetable of Line 217  
at the Fairfax/Beverly Stop

TYPE OF HEADWAYS :EQUAL (1)

TIMETABLE

TYPE OF TIMETABLE:ONE METHOD (1)

\*\*\*\*\*

METHOD NUMBER: 2 FROM INTERVAL: 1 TO INTERVAL: 19

CLOCK HEADWAYS: NO (0)

		DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME
MAX	4				
MAX	6	1	6.00	46	13.23
MAX	7	2	6.25	47	13.30
MAX	9	3	6.49	48	13.38
MAX	9	4	7.06	49	13.45
MAX	10	5	7.18	50	13.53
MAX	10	6	7.29	51	14.00
MAX	10	7	7.41	52	14.06
MAX	10	8	7.52	53	14.12
MAX	11	9	8.03	54	14.19
MAX	11	10	8.14	55	14.25
MAX	11	11	8.24	56	14.31
MAX	12	12	8.34	57	14.37
MAX	12	13	8.44	58	14.43
MAX	12	14	8.55	59	14.49
MAX	12	15	9.04	60	14.55
MAX	12	16	9.13	61	15.02
MAX	12	17	9.22	62	15.08
MAX	12	18	9.31	63	15.14
MAX	12	19	9.39	64	15.21
MAX	12	20	9.48	65	15.27
MAX	14	21	9.57	66	15.34
MAX	14	22	10.05	67	15.40
MAX	14	23	10.13	68	15.46
MAX	14	24	10.20	69	15.53
MAX	14	25	10.28	70	15.59
MAX	14	26	10.36	71	16.14
MAX	14	27	10.43	72	16.29
MAX	14	28	10.51	73	16.44
MAX	14	29	10.59	74	16.59
MAX	14	30	11.07	75	17.21
MAX	14	31	11.16	76	17.42
MAX	14	32	11.24	77	18.04
MAX	14	33	11.33	78	18.31
MAX	14	34	11.42	79	18.57
MAX	14	35	11.50	80	19.27
MAX	14	36	11.59	81	19.58
MAX	14	37	12.08	82	20.28
MAX	15	38	12.17	83	20.58
MAX	15	39	12.25	84	21.28
MAX	16	40	12.34	85	21.59
MAX	16	41	12.43	86	22.29
MAX	18	42	12.52	87	22.59
MAX	18	43	13.01	88	23.29
MAX	18	44	13.08	89	24.00
MAX	19	45	13.16	90	0.30
MAX	19			91	1.00
MAX	19				
MAX	19				

COMPARISON MEASURES

\*\*\*\*\*

TOTAL NUMBER OF DEPARTURES: 91

Table 27 Computer Generated Timetable of Line 217  
at the Fairfax/Beverly Stop

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

\*\*\*\*\*

DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME
1	6.00	37	13.27
2	6.29	38	13.37
3	6.58	39	13.48
4	7.12	40	13.59
5	7.25	41	14.09
6	7.38	42	14.18
7	7.50	43	14.28
8	8.03	44	14.38
9	8.15	45	14.47
10	8.27	46	14.57
11	8.39	47	15.06
12	8.50	48	15.14
13	9.02	49	15.23
14	9.13	50	15.31
15	9.24	51	15.40
16	9.35	52	15.49
17	9.46	53	15.57
18	9.57	54	16.12
19	10.08	55	16.29
20	10.18	56	16.47
21	10.28	57	17.06
22	10.38	58	17.31
23	10.48	59	17.56
24	10.58	60	18.25
25	11.09	61	18.55
26	11.20	62	19.26
27	11.31	63	19.56
28	11.42	64	20.27
29	11.53	65	20.57
30	12.04	66	21.27
31	12.16	67	21.58
32	12.28	68	22.28
33	12.41	69	22.58
34	12.53	70	23.29
35	13.05	71	23.59
36	13.16	72	0.30
		73	1.00

COMPARISON MEASURES

\*\*\*\*\*

TOTAL NUMBER OF DEPARTURES: 73

MINIMUM SINGLE ROUTE (ROUND TRIP) REQUIRED FLEET SIZE 13



Table 28 Computer Generated Timetable of Line 217  
at the Fairfax/Beverly Stop

TYPE OF HEADWAYS :EQUAL (1)

TYPE OF TIMETABLE:ONE METHOD (1)

METHOD NUMBER: 2 FROM INTERVAL: 1 TO INTERVAL: 19

CLOCK HEADWAYS :YES (1)

TIMETABLE

\*\*\*\*\*

DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME
1	6.00	46	13.30
2	6.30	47	13.37
3	7.00	48	13.45
4	7.12	49	13.52
5	7.24	50	14.00
6	7.36	51	14.06
7	7.48	52	14.12
8	8.00	53	14.18
9	8.10	54	14.24
10	8.20	55	14.30
11	8.30	56	14.36
12	8.40	57	14.42
13	8.50	58	14.48
14	9.00	59	14.54
15	9.10	60	15.00
16	9.20	61	15.06
17	9.30	62	15.12
18	9.40	63	15.18
19	9.50	64	15.24
20	10.00	65	15.30
21	10.07	66	15.36
22	10.15	67	15.42
23	10.22	68	15.48
24	10.30	69	15.54
25	10.37	70	16.00
26	10.45	71	16.15
27	10.52	72	16.30
28	11.00	73	16.45
29	11.07	74	17.00
30	11.15	75	17.20
31	11.22	76	17.40
32	11.30	77	18.00
33	11.37	78	18.30
34	11.45	79	19.00
35	11.52	80	19.30
36	12.00	81	20.00
37	12.10	82	20.30
38	12.20	83	21.00
39	12.30	84	21.30
40	12.40	85	22.00
41	12.50	86	22.30
42	13.00	87	23.00
43	13.07	88	23.30
44	13.15	89	24.00
45	13.22	90	0.30
		91	1.00

COMPARISON MEASURES

\*\*\*\*\*

TOTAL NUMBER OF DEPARTURES: 91

MINIMUM SINGLE ROUTE (ROUND TRIP) REQUIRED FLEET SIZE 20

Table 29 Computer Generated Timetable of Line 217  
at the Fairfax/Beverly Stop

TYPE OF HEADWAYS : BALANCED (2)

TYPE OF TIMETABLE: ONE METHOD (1)

METHOD NUMBER: 2 FROM INTERVAL: 1 TO INTERVAL: 19

CLOCK HEADWAYS: NO (0)

TIMETABLE

\*\*\*\*\*

DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME
1	6.00	46	13.19
2	6.32	47	13.25
3	6.56	48	13.30
4	7.09	49	13.38
5	7.23	50	13.52
6	7.35	51	14.00
7	7.43	52	14.06
8	7.52	53	14.09
9	8.02	54	14.12
10	8.08	55	14.16
11	8.21	56	14.22
12	8.31	57	14.29
13	8.40	58	14.37
14	8.55	59	14.48
15	9.07	60	14.55
16	9.17	61	15.01
17	9.24	62	15.03
18	9.32	63	15.06
19	9.39	64	15.10
20	9.50	65	15.16
21	9.57	66	15.23
22	10.08	67	15.32
23	10.13	68	15.42
24	10.18	69	15.50
25	10.25	70	15.59
26	10.34	71	16.14
27	10.39	72	16.28
28	10.51	73	16.43
29	10.59	74	17.00
30	11.07	75	17.15
31	11.15	76	17.36
32	11.22	77	18.04
33	11.29	78	18.24
34	11.43	79	18.47
35	11.50	80	19.21
36	11.59	81	19.58
37	12.09	82	20.28
38	12.20	83	20.55
39	12.29	84	21.38
40	12.35	85	21.58
41	12.45	86	22.23
42	12.53	87	23.00
43	13.01	88	23.19
44	13.09	89	24.00
45	13.14	90	0.28
		91	0.58

COMPARISON MEASURES

\*\*\*\*\*

TOTAL NUMBER OF DEPARTURES: 91

MINIMUM SINGLE ROUTE (ROUND TRIP) REQUIRED FLEET SIZE 20

Table 30 Computer Generated Timetable of Line 217  
at the Fairfax/Beverly Stop

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

\*\*\*\*\*

DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME
1	6.00	37	13.20
2	6.36	38	13.28
3	6.59	39	13.42
4	7.14	40	13.58
5	7.29	41	14.08
6	7.40	42	14.14
7	7.49	43	14.20
8	8.02	44	14.33
9	8.11	45	14.46
10	8.24	46	14.56
11	8.35	47	15.03
12	8.48	48	15.08
13	9.04	49	15.16
14	9.16	50	15.26
15	9.27	51	15.38
16	9.38	52	15.46
17	9.50	53	15.57
18	9.58	54	16.13
19	10.10	55	16.28
20	10.15	56	16.45
21	10.27	57	17.07
22	10.37	58	17.27
23	10.49	59	17.54
24	10.59	60	18.19
25	11.11	61	18.48
26	11.20	62	19.19
27	11.30	63	19.57
28	11.44	64	20.21
29	11.55	65	20.54
30	12.03	66	21.32
31	12.17	67	21.57
32	12.31	68	22.24
33	12.43	69	22.59
34	12.54	70	23.20
35	13.05	71	23.59
36	13.13	72	0.20
		73	0.58

COMPARISON MEASURES

\*\*\*\*\*

TOTAL NUMBER OF DEPARTURES: 73

MINIMUM SINGLE ROUTE (ROUND TRIP) REQUIRED FLEET SIZE 13

tables appear in Appendix D. In program II a printout option exists to observe the procedure to determine the minimum required fleet size for a single route without short-turns. This printout is displayed in Tables 21 and 26. The program simply determines for each departure the amount of different buses that depart before it can resume another departure, and considers the maximum of all of these amounts associated with the earlier departures. That is, in Table 21 the 38th departure determined the minimum fleet size of 15 buses.

Several observations can be made from the results presented in Table 20. The results of Method 4 indicate significant resource saving in comparison to the results of Method 2 particularly in the south direction. This observation can be also seen in Figure 17. The combinations of methods used in the 5th, 14th, 21st and the 30th computer runs indicate that the use of Method 4 during only peak periods does not result in significant saving in comparison with Method 2 results. In fact the fleet size remains the same. Consequently, the conclusion that can be drawn is that Method 4 may be particularly useful during off-peak hours -- an observation which again can be seen in Figure 17. For the south 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 open an opportunity to introduce the clock headway timetable shown in Table 28 at the Fairfax/Beverly stop. It is worth mentioning that the clock headway pattern is not maintained along the entire route due to different running times between timepoints. An additional interesting observation is that by eliminating the number of departures to 70 and using Method 2 (31st computer run) one obtains a fleet size measure higher than by using Method 4 without restrictions (29th run) for the case of balanced headway in the south direction. Table 20 also demonstrates, as expected, the tendency of the comparison measures to be the same for equal and balanced headways.

Certainly, the large number and variety of timetables may complicate the decision process of the schedulers. However, it opens an opportunity to examine rapidly different timetable and frequency scenarios. It is anticipated, however, that the skilled scheduler will select only a few alternatives to compare while recognizing the full potential of the procedures. A future task of this "applications for ADCS" project (see next chapter) involves interaction with the SCRTD schedulers regarding the results presented in this chapter and the Appendices.

## **Chapter 7: Conclusion and Future Tasks**

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This document presents one component of an extensive program to develop applications for bus Automatic Data Collection systems (ADCS). The overall description of the program is displayed in a flowchart in Figure 1 of the first chapter. This study, basically, provides alternative methods for constructing bus timetables using passenger load data. The procedures developed are accompanied by a step-by-step explanation using the same scheduling example throughout the entire report. This description is intended both to serve as a guideline for adequately using the methods (even for a novice scheduler) and to allow for a scheduler's response in order to refine and adjust the procedures as part of future endeavors.

Five major objectives of the overall program to develop applications for ADCS were identified in Section 1.1. This study is related directly to two objectives: (i) improve management and operations through research by developing, improving, validating and testing models and procedures for the bus operational planning process, and (ii) improve productivity and efficiency by matching supply and demand. The specific contributions of this study to these two objectives and the possible future tasks of the "applications for ADCS" program are described in the following two sections.

### **7.1 Conclusions**

Six objectives are set in Section 1.2 for this study. The procedures developed attempt to fully accomplish these

objectives. The final product, described in Chapter 6, consists of a set of computer programs that perform:

- (i) conversion from the bus property (SCRTD) main-frame files to an adequate input file,
- (ii) analysis of four methods for setting bus frequencies,
- (iii) creation of alternative timetables at a single timepoint, and
- (iv) creation of a public timetable at all the route timepoints (this program is still in preparation).

It is planned to initially test this product at SCRTD in Los Angeles. The new and computerized techniques to derive bus frequencies and construct alternative timetables will be evaluated at two levels: (1) their appropriateness for routes with non-ADCS equipped buses in which the data is gathered manually, (2) their appropriateness for routes with ADCS in which the data is automatically generated. Undoubtedly, with the anticipated reliable and vast amount of passenger load data from the ADCS it will be possible to systematically investigate the variations of passenger demand. However, it is not likely that in the near future all the routes will be operated by ADCS equipped buses. On the other hand the computer scheduling files will probably be based on one system rather than on two systems which distinguish routes with and without ADCS. Therefore, careful attention must also be given to routes without ADCS.

The outcome of this work can be generally described in light of the six study objectives set forth in Section 1.2. The procedures developed provide alternative timetables in terms of bus departure times at one timepoint. Each timetable is accompanied by two comparison measures which are used as an evaluation indicator in conjunction with resource saving. The first measure is the total required bus runs (departures) and the second is the minimum required fleet size at the route

level. These evaluation measures fulfill the first objective. One set of options in selecting the procedure to construct the timetables is referred to as balancing passenger loads on individual buses while allowing unevenly spaced headways. The underlying approach in this set of options is to shift departure times of individual buses so that to obtain even average loads instead of even headways. In addition, this procedure ensures that while shifting the departure times the number of bus runs and the minimum fleet size at the route level are maintained. This balancing the loads approach fulfills the second objective.

The third objective of the study is to provide flexible and alternative timetables to be used in a practical scheduling environment. This objective is fulfilled by permitting the scheduler to request different timetables from a variety of possible combinations (shown in Figure 3). By simply key-punching approximately 5 digits the scheduler can request equal or balanced (uneven) headways, combinations of frequency setting methods, clock or the derived headways and also to pre-specify the number of departures. Part of the input to the timetable construction program is based on different sets of frequencies (usually non-integer derived values). The scheduler can either interject his own set of intuitive-or experience-based frequencies, or can substitute some of the derived frequencies. In this manner possible scheduling exceptions (e.g., special passenger demand due to a sport event) could be accomplished to fulfill the fourth study's objective.

The common manual process to create timetables is often encountered by a problem in smoothing the headways in the transition segments between adjacent time periods. The procedure to simply average the transitional headways does not guarantee that the average observed loads will not exceed the desired bus occupancy. The procedure developed for both the equal and balanced headways ensure, in an average sense, the fulfillment of the desired occupancy constraint -- the



necessity expressed in the fifth objective of this study. The sixth and last objective is fulfilled by allowing the user (scheduler) to request the selection of different frequency setting methods for different time periods. In this way the scheduler can select for peak periods methods which are more sensitive to resource saving (e.g., see Method 4 in Chapter 3) and for off-peak periods methods which are more sensitive to passenger comfort (e.g., see Method 2 in Chapter 3).

## 7.2 Future Research Tasks

Future research tasks can be grouped into six categories in compliance with the outlined program in Figure 1 to develop applications for ADCS. In what follows is a brief description of these six major task categories.

### (i) Construction of alternative timetables including route design elements

This category represents a direct extension of the study reported here. It includes interaction with the schedulers of SCRTD and perhaps other bus properties regarding the potential use of the various programs developed in this work. Based on the schedulers' evaluation the programs will be further refined and modified.

Under this category further development of a microcomputer based scheduling system will take place. An initial development of a microcomputer version for constructing bus timetables is reported by Stern in Reference 12. Stern's product, named TSC LINE SCHEDULER, demonstrates the generation of headway sheets and public timetables (at all timepoints) for the hourly max load procedure (Method 2). Extensions and modifications for this initial work can be classified under issues of: Flexible options to construct timetables, data base, information query system, evaluation procedures, report generation, and incorporation with other scheduling tasks. Reference 12 further interpret these issues.

A major task in this category is to efficiently determine possible short turns for a given urban bus route (a crosstown line). One comparison measure used in this work is the minimization of the required fleet size on a single route without short turns. However, the possibility to generate shortlines (or branches) open the opportunity to save buses while ensuring that the loads in each route segment will not exceed the desired occupancy. On the other hand the common used procedure by bus properties to determine short turns is based only on visual observation of the load profile. A potential new turn point or new route departure point is determined at the nearest adequate timepoint to a point in which a sharp decrease or increase in passenger load is observed. This procedure is intuitively correct. However, the schedulers do not know if actually all the short turns are needed to reduce the minimum required buses. A future task can investigate this issue while attempting to fulfill the objective of minimizing the number of short turns provided that the minimum fleet size is maintained. In this way the maximum benefit will be attained to both operator and passengers.

(ii) Dynamic Patterns: Variability of passenger loads and running times

This category includes tasks to analyze extensive amounts of running time and load data collected by ADCS. The purpose of this task category is three-fold:

- (i) to organize the ADCS data in a manageable and adequate form in conjunction with the input data required for schedule construction and adjustments;
- (ii) to recommend the amount and type of running time and load data that need to be stored;
- (iii) to address and attempt to answer the question of how often to update the ride check and point check data using various sampling techniques.

The basic organized and filed data shall include valid statistical measures (e.g., mean and standard deviation) of the running times and loads by day-of-the-week, time of day, location and direction of travel. These measures will be accompanied by additional information: number of buses from which the data were collected, type of buses, route number, desired occupancy (load factor), headway policy, distances between stops, information about individual drivers and other useful characteristics.

Time-series and other statistical analyses shall be performed on the organized data. This investigation may include:

- (a) to screen out inadequate data (outliners, incomplete information, etc.)
- (b) to identify probability density functions for the ride check (load profile and running time for each segment) and point check (max load stop) data
- (c) to establish patterns of variations (significant differences) regarding load profile, max load and running time data
- (d) to perform a trend analysis on cyclic effects and singular events, weekly and seasonal effects and weekends and holiday effects

(iii) Impact of run times on practical schedule development methods

This task category shall address the relationship between run time data and its variability and bus scheduling methods.

The purpose of these tasks is four-fold:

- (i) to identify all the components in the scheduling tasks that are dependent on bus running times;
- (ii) to establish the desired input running time data for each component identified in (i)
- (iii) to develop deterministic and stochastic methods for adequately arranging the running time (input) data for each related scheduling procedure

- (iv) to examine the variation of the irregularity sources that affect the running time variation.

These tasks primarily involve a review of bus properties to identify various scheduling approaches in which the running time data are considered. One such approach, utilized in Los Angeles, is to consider different running times between each two timepoints. This information is used for creating the timetables (departure times) by going backward and forward from the max load timepoint to all the other timepoints.

This category shall particularly emphasize the required running time data (in format and amount) for the bus scheduling (block generation) tasks. The specified data should ease the scheduler's task of minimizing the number of blocks for a given timetable.

In addition to preparing adequate running time input for the scheduling components, these tasks shall attempt to construct a model that exhibits reliability issues in terms of run time variability sources. The model may evaluate changes in the running times based on the following five sources of run time variability: (1) different number of boarding passengers, (2) different boarding times of passengers, (3) different travel times between bus stops, (4) probability of buses stopping at stop, and (5) undisciplined departures from terminals.

(iv) Simulation of bus routes for scheduling improvements

This task category shall develop a bus simulation model capable of analyzing alternative schedules and schedule adjustments. The basic input data for the model will be supplied by the ADCS in Los Angeles. The purpose of these tasks is twofold:

- (i) to examine alternative schedules and to determine the best schedule in terms of resource saving while providing adequate level of service to the passengers;

- (ii) to provide an analytical tool for efficiently evaluating various dispatching, regulating and other operational strategies.

Initial development of these tasks is presently performed by Marguier and Wilson (Ref. 13). They established an initial simulation model and are now in the process of extending it with the use of SCRTD ride check data.

The fully developed simulation model should be based upon verified stochastic processes including: (1) passenger arrival patterns, (2) bus running times, (3) passenger boarding and alighting times, (4) bus dwell times, and (5) passenger waiting strategies for overlapping sections. In addition, the simulation model should be flexible enough to allow different traffic conditions in order to assess crucial measures such as delay and disruption. Prior to the simulation runs, the ADCS data should be analyzed with respect to the variability of passenger demand and bus running times by day-of-the-week, time of day, location, direction of travel and possibly variations among drivers.\* The output of this analysis will be part of the input to the simulation model in order to test different variation scenarios.

This research may also evaluate alternative schedules and various control tactics for three types of route operation:

- (a) single route with two dispatching points
- (b) two routes with three dispatching points (with possible overlapped end/start segment)
- (c) two routes with four dispatching points (with an overlapped mid-segment)

Data for the first type and partially for the second type are available from the ADCS in Los Angeles. The remaining route operations should determine (given a schedule and control

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\* See category (ii)

tactic) the required number of bus runs, the required fleet size, bus utilization and measures of passenger level of service.

(v) Bus scheduling Optimization (generation of blocks):  
Graphical and interactive techniques

This category shall exploit, to the greatest extent possible, the capabilities of a graphical interactive vehicle scheduling procedure on both the mainframe -- and micro-computers, for improving the process of assigning buses to trips. The purpose of these tasks is three-fold:

- (i) to develop a graphical representation (display) of the vehicle schedule in a way that it will serve as a diagnostic tool to improve scheduling (reduction of the required fleet size or the number of blocks)
- (ii) to improve the quality of information available to the schedulers, i.e., to prepare adequate input data and explicit data display (e.g., trip time and its variability, indication of the required trips by type, dead-heading time matrix, etc.)
- (iii) to allow for a man-machine interactive approach using three modes of operations: manual, automatic and the combination of automatic and manual.

The input to the developed techniques should be based on: Trip Time Variability, a given Timetable (departure times and estimated arrival times), Departure Time Tolerances (intervals in which the scheduler is allowed to adjust departure times), Dead-Heading Times, and Garage locations and characteristics. The output of the program will consist of: Revised Timetable, Fleet Size, Bus Assignments (blocks) and Garage Status.

The main scheduling program will be comprised of five phases:

- (a) Graphical display construction and file manipulation.

- (b) Fleet reduction through shortening trip times and shifting departure times.
- (c) Fleet reduction through inserting dead-heading trips (with shifting)
- (d) Balancing dead-heading trips according to garage and depot capacity.
- (e) Generation of alternative block constructions.

After developing the program, the procedures should be tested with Los Angeles Data. The final task in this category is to evaluate the accuracy and practicability of the suggested scheduling techniques.

- (vi) Improving the Route Level Management: Evaluation of short-term scheduling changes as substituted for operational controls

This task category shall be based on experiments to be performed directly with the ADCS in Los Angeles. The purpose of these tasks is three-fold:

- (i) to test various operational tactics (through radio communications) to control appropriately the bus movements
- (ii) to prepare experience-based guidelines for the supervisors (dispatchers) regarding the use of adequate control tactics
- (iii) to evaluate whether these operational situations can be effectively dealt with through short-term scheduling changes

This project will be comprised of 5 main phases:

- (a) preparing work plan to be implemented to the ADCS control room in Los Angeles
- (b) testing the various control strategy scenarios
- (c) analyzing the ADCS data
- (d) performing a second test (if required)
- (e) preparation of guidelines

The work plan should consist of list of tactics to be applied separately, a list of combination of tactics to be applied, the length of time to test each control strategy, and description of the locations and situations in which the tactics will be used. This plan should be carefully built in a systematic manner together with experienced planners and field supervisors.

It is anticipated that the developed guidelines will enable the dispatcher to use control strategies as preventive actions as well as tools for corrective action. The possible tactics that can be tested are:

- (1) hold buses at particular points;
- (2) decide about coordinate and uncoordinated skip stops;
- (3) change trip start time;
- (4) adjust schedule;
- (5) transfer passengers and turn particular buses;
- (6) decide on passenger "discharge only" operation;
- (7) change to nonstop or express mode;
- (8) switch drivers (or crew);
- (9) use standby drivers (or crew);
- (10) insert standby buses into service;
- (11) operate "out of service" buses to particular points; and
- (12) alter route temporarily.

These six categories of future tasks will attempt to demonstrate the possible benefits that can occur to both operators and passengers when using new and improved procedures for bus operations planning. The procedures to be developed will be especially based on ADCS. Undoubtedly, as these research tasks will take place more knowledge will be gained and further uses of the new ADCS technology will emerge.



## References

1. "Computer Scheduling of Public Transport: Urban Passenger Vehicle and Crew Scheduling", A. Wren (Ed.), North-Holland Publishing Company, 1981.
2. "Third International Workshop on Transit Vehicle and Crew Scheduling", proceedings, University of Montreal, Transportation Research Center, June 27-30, 1983 (to be issued by North-Holland Publication Company).
3. Ceder, A. and Gonen, D. "The Operational Planning Process of a Bus Company", UITP Review, vol. 29, No. 3, pp. 199-218, 1980.
4. Ceder, A. "Setting Bus Headways: Methods and Appraisal" Transportation Systems Center, working paper #67-U.3-1, September, 1982 (forthcoming in Transportation Research part A journal).
5. "ADCS Monitor: Draft Functional Specifications and User Guide", Multisystems, UMTA/TSC Service and Management Demonstration Program, June 1983.
6. Vozzolo, D. and Attanucci, J. "An Assessment of Automatic Passenger Counters" Interim Report, Multisystems, Report Number DOT-I-82-43, prepared for Urban Mass Transportation Administration, September 1982.
7. Furth, P.G. and Wilson N.H.M. "Setting Frequencies on Bus Routes: Theory and Practice", Transportation Research Record 818, pp. 1-7, 1981.
8. Koutsopoulos, H.N., Odoni, A. and Wilson, N.H.M. "Determination of Headways as a function of Time Varying Characteristics on a Transit Network" appears in Reference #2 above.
9. Lampkin, M. and Saalmans, P.D. "The Design of Routes, Service Frequencies, and Schedules for a Municipal Bus Undertaking: A Case Study" Operation Research Quarterly, Vol. 18, No. 4, pp. 375-397, 1967.
10. Ceder, A. "Practical Methodology for Determining Dynamic Changes in Bus Travel Times" Transportation Research Record 787, pp. 18-22, 1981.
11. Salzborn, F.J.M. "Optimum Bus Scheduling" Transportation Science, Vol. 6. pp. 137-148, 1972.
12. Stern, H. "The TSC Line Scheduler: A Microcomputer Interactive Program for the Creation and Evaluation of Bus Timetables from Passenger Load Data" Progress Report Transportation Systems Center, Service Assessment Division, September 1983.

### References

13. Marguier, P. and Wilson, N. "Status of Bus Simulation Model Development for the Scheduling Functions" Draft Memo, M.I.T., Cambridge, September 1983.





## **Appendix B: Data for Program II (Bustime)**

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The BUSTIME program reads two data files. The first is a parameter file consisting of the following data:

- A. Headway Switch -- one record containing the switch:
  - 1 = equal headways
  - 2 = balanced headways
  
- B. Number of Operating Options -- one record containing the number of options.
  
- C. Methods Data -- one record per option with the following data:
  - 1. First period in which the option is operated.
  - 2. Last period in which the option is operated.
  - 3. Method used to determine frequency.
  
- D. Clock Headway Switch -- one record containing the switch:
  - 1 = clock headways
  - 0 = otherwise
  
- E. Specified Departures -- one record containing a specified number of daily trips, or a "0" if trips are not specified.

An example is shown below where method 4 is used in the peaks and method 2 during the rest of the day.

2  
5  
2 1 1  
4 2 3  
2 4 11  
4 12 13  
2 14 19  
0  
0

The second file read by BUSTIME is a data file produced by the RIDCHK program. The file prepared for route 217 (northbound) is shown on the following pages as an example.

The file consists of the following groups of records:

A. Sizes -- one record containing the following data:

1. Number of time periods
2. Number of methods
3. Number of "trips" (including dummy trips at end of each period).

B. Time Period Data -- one record for each time period containing the following data:

1. Period number
2. Start time
3. End time
4. Duration (in minutes)
5. Cycle time including layover (in minutes)
6. Bus frequency calculated using each method.

C. Trip Data -- one record for each trip containing the following data:

1. Period number
2. Trip number
3. Time of previous trip
4. Time of trip
5. Interval from previous trip (in minutes)
6. Load at daily maximum load point
7. Load at period maximum load point
8. Passenger-kilometers
9. Passenger-kilometers

19	4	135							
1	06.00	07.00	60	77	2.00	2.00	2.00	2.00	
2	07.00	08.00	60	98	5.29	5.73	5.01	5.11	
3	08.00	09.00	60	96	4.66	5.29	4.63	4.72	
4	09.00	10.00	60	96	4.10	4.10	3.07	3.07	
5	10.00	11.00	60	108	5.76	5.82	3.64	4.93	
6	11.00	12.00	60	108	5.84	5.84	3.65	5.03	
7	12.00	13.00	60	108	6.54	7.62	4.76	6.16	
8	13.00	14.00	60	118	7.52	7.70	4.81	7.21	
9	14.00	15.00	60	118	7.34	7.46	4.66	6.96	
10	15.00	16.00	60	114	6.97	7.12	5.34	6.73	
11	16.00	17.00	60	114	6.87	6.87	6.01	6.01	
12	17.00	18.00	60	114	5.30	5.39	4.71	4.90	
13	18.00	19.00	60	114	3.57	3.67	2.75	3.25	
14	19.00	20.00	60	98	2.00	2.00	2.00	2.00	
15	20.00	21.00	60	98	2.00	2.00	2.00	2.00	
16	21.00	22.00	60	98	2.00	2.00	2.00	2.00	
17	22.00	23.00	60	98	2.00	2.00	2.00	2.00	
18	23.00	24.00	60	98	2.00	2.00	2.00	2.00	
19	24.00	25.00	60	98	2.00	2.00	2.00	2.00	
1	1	06.00	06.04	4	0	0	7	7	
1	2	06.04	06.18	14	0	0	9	9	
1	3	06.18	06.30	12	14	18	117	117	
1	4	06.30	06.40	10	18	23	149	149	
1	5	06.40	06.48	8	5	1	33	33	
1	6	06.48	06.56	8	8	28	127	127	
1	7	06.56	07.00	4	4	0	10	10	
2	8	07.00	07.03	3	3	2	10	10	
2	9	07.03	07.11	8	32	31	236	236	
2	10	07.11	07.19	8	15	16	83	83	
2	11	07.19	07.28	9	51	54	357	357	
2	12	07.28	07.35	7	29	39	117	117	
2	13	07.35	07.40	5	40	45	172	172	
2	14	07.40	07.44	4	38	43	258	258	
2	15	07.44	07.47	3	22	23	53	53	
2	16	07.47	07.53	6	63	67	391	391	
2	17	07.53	07.59	6	70	72	267	267	
2	18	07.59	08.00	1	7	9	64	64	
3	19	08.00	08.07	7	54	67	447	447	
3	20	08.07	08.14	7	55	65	406	406	
3	21	08.14	08.22	8	26	36	256	256	
3	22	08.22	08.29	7	20	16	108	108	
3	23	08.29	08.36	7	43	47	323	323	
3	24	08.36	08.44	8	60	71	372	372	
3	25	08.44	08.52	8	37	45	192	192	
3	26	08.52	09.00	8	31	23	109	109	
4	27	09.00	09.07	7	51	51	352	352	
4	28	09.07	09.15	8	28	28	144	144	
4	29	09.15	09.22	7	34	34	292	292	
4	30	09.22	09.30	8	33	33	159	159	
4	31	09.30	09.37	7	33	33	276	276	
4	32	09.37	09.45	8	23	23	91	91	
4	33	09.45	09.52	7	17	17	116	116	
4	34	09.52	10.00	8	27	27	159	159	
5	35	10.00	10.07	7	28	37	226	226	

5	36	10.07	10.15	8	32	23	140	140
5	37	10.15	10.22	7	30	33	201	201
5	38	10.22	10.31	9	36	31	196	196
5	39	10.31	10.38	7	41	50	266	266
5	40	10.38	10.45	7	35	33	166	166
5	41	10.45	10.52	7	37	31	185	185
5	42	10.52	11.00	8	49	53	241	241
6	43	11.00	11.08	8	21	21	192	192
6	44	11.08	11.16	8	63	63	296	296
6	45	11.16	11.23	7	51	51	220	220
6	46	11.23	11.31	8	20	20	108	108
6	47	11.31	11.38	7	35	35	291	291
6	48	11.38	11.46	8	34	34	145	145
6	49	11.46	11.53	7	33	33	198	198
6	50	11.53	12.00	7	35	35	166	166
7	51	12.00	12.01	1	5	2	24	24
7	52	12.01	12.08	7	44	80	335	335
7	53	12.08	12.16	8	52	50	263	263
7	54	12.16	12.23	7	18	25	193	193
7	55	12.23	12.31	8	53	53	211	211
7	56	12.31	12.38	7	48	53	381	381
7	57	12.38	12.46	8	50	43	287	287
7	58	12.46	12.53	7	28	44	212	212
7	59	12.53	13.00	7	29	31	122	122
8	60	13.00	13.01	1	4	3	17	17
8	61	13.01	13.08	7	82	77	551	551
8	62	13.08	13.16	8	49	60	256	256
8	63	13.16	13.23	7	34	44	250	250
8	64	13.23	13.31	8	64	46	305	305
8	65	13.31	13.38	7	27	40	250	250
8	66	13.38	13.46	8	21	32	157	157
8	67	13.46	13.53	7	50	46	303	303
8	68	13.53	14.00	7	45	37	270	270
9	69	14.00	14.01	1	6	5	38	38
9	70	14.01	14.10	9	71	69	472	472
9	71	14.10	14.18	8	52	43	260	260
9	72	14.18	14.26	8	9	9	123	123
9	73	14.26	14.33	7	52	57	240	240
9	74	14.33	14.40	7	59	52	398	398
9	75	14.40	14.47	7	18	16	88	88
9	76	14.47	14.54	7	40	46	282	282
9	77	14.54	15.00	6	40	49	226	226
10	78	15.00	15.02	2	14	13	78	78
10	79	15.02	15.09	7	24	39	314	314
10	80	15.09	15.15	6	0	13	62	62
10	81	15.15	15.16	1	59	59	340	340
10	82	15.16	15.24	8	61	51	407	407
10	83	15.24	15.32	8	30	35	218	218
10	84	15.32	15.39	7	73	71	517	517
10	85	15.39	15.46	7	58	58	262	262
10	86	15.46	15.53	7	37	33	228	228
10	87	15.53	16.00	7	62	55	249	249
11	88	16.00	16.07	7	67	67	380	380
11	89	16.07	16.14	7	59	59	330	330
11	90	16.14	16.21	7	22	22	167	167



11	91	16.21	16.28	7	60	60	290	290
11	92	16.28	16.35	7	83	83	529	529
11	93	16.35	16.42	7	27	27	111	111
11	94	16.42	16.49	7	91	91	508	508
11	95	16.49	16.56	7	34	34	183	183
11	96	16.56	17.00	4	38	38	317	317
12	97	17.00	17.03	3	29	31	237	237
12	98	17.03	17.10	7	35	37	212	212
12	99	17.10	17.17	7	48	42	294	294
12	100	17.17	17.24	7	78	78	412	412
12	101	17.24	17.31	7	36	38	270	270
12	102	17.31	17.38	7	20	23	141	141
12	103	17.38	17.45	7	23	23	183	183
12	104	17.45	17.52	7	45	49	210	210
12	105	17.52	18.00	8	57	56	462	462
13	106	18.00	18.09	9	17	18	91	91
13	107	18.09	18.18	9	52	56	374	374
13	108	18.18	18.27	9	25	25	139	139
13	109	18.27	18.37	10	41	42	297	297
13	110	18.37	18.47	10	36	37	216	216
13	111	18.47	18.56	9	36	36	200	200
13	112	18.56	19.00	4	7	6	52	52
14	113	19.00	19.06	6	10	9	81	81
14	114	19.06	19.17	11	19	22	145	145
14	115	19.17	19.33	16	24	25	163	163
14	116	19.33	19.45	12	20	21	135	135
14	117	19.45	19.59	14	27	27	207	207
14	118	19.59	20.00	1	2	2	10	10
15	119	20.00	20.14	14	17	18	135	135
15	120	20.14	20.34	20	21	22	108	108
15	121	20.34	20.54	20	13	12	87	87
15	122	20.54	21.00	6	6	7	41	41
16	123	21.00	21.14	14	17	10	95	95
16	124	21.14	21.34	20	14	16	145	145
16	125	21.34	21.54	20	14	26	121	121
16	126	21.54	22.00	6	5	4	40	40
17	127	22.00	22.14	14	13	13	98	98
17	128	22.14	22.44	30	28	28	181	181
17	129	22.44	23.00	16	10	10	93	93
18	130	23.00	23.14	14	9	10	79	79
18	131	23.14	23.44	30	7	8	57	57
18	132	23.44	24.00	16	4	4	35	35
19	133	24.00	24.14	14	3	5	31	31
19	134	24.14	24.44	30	4	2	15	15
19	135	24.44	25.00	16	1	2	6	6
19	136	25.00	25.00	0	0	0	0	0

19 4 141

1	06.00	07.00	60	77	2.40	2.45	2.00	2.10
2	07.00	08.00	60	96	4.71	5.30	4.64	4.73
3	08.00	09.00	60	96	5.63	5.86	5.13	5.13
4	09.00	10.00	60	96	6.67	6.93	5.20	5.49
5	10.00	11.00	60	108	7.84	7.84	4.90	6.00
6	11.00	12.00	60	108	6.68	7.04	4.40	5.60
7	12.00	13.00	60	108	6.80	6.80	4.25	4.95
8	13.00	14.00	60	118	7.56	8.16	5.10	5.58
9	14.00	15.00	60	118	9.70	9.86	6.16	6.36
10	15.00	16.00	60	114	9.42	9.42	7.06	7.06
11	16.00	17.00	60	114	3.87	3.97	3.47	3.47
12	17.00	18.00	60	114	2.70	2.81	2.46	2.46
13	18.00	19.00	60	114	2.13	2.28	2.00	2.00
14	19.00	20.00	60	98	2.00	2.00	2.00	2.00
15	20.00	21.00	60	98	2.00	2.00	2.00	2.00
16	21.00	22.00	60	98	2.00	2.00	2.00	2.00
17	22.00	23.00	60	98	2.00	2.00	2.00	2.00
18	23.00	24.00	60	98	2.00	2.00	2.00	2.00
19	24.00	25.00	60	98	2.00	2.00	2.00	2.00
1	1	06.00	06.02	2	19	19	133	133
1	2	06.02	06.17	15	10	8	58	58
1	3	06.17	06.29	12	27	28	205	205
1	4	06.29	06.40	11	18	19	98	98
1	5	06.40	06.47	7	26	30	247	247
1	6	06.47	06.56	9	17	17	70	70
1	7	06.56	07.00	4	27	26	141	141
2	8	07.00	07.03	3	20	17	105	105
2	9	07.03	07.11	8	26	32	203	203
2	10	07.11	07.19	8	44	45	324	324
2	11	07.19	07.26	7	35	30	158	158
2	12	07.26	07.35	9	58	56	367	367
2	13	07.35	07.43	8	52	69	326	326
2	14	07.43	07.52	9	53	75	502	502
2	15	07.52	08.00	8	42	47	200	200
3	16	08.00	08.07	7	80	88	422	422
3	17	08.07	08.15	8	35	26	276	276
3	18	08.15	08.23	8	55	65	309	309
3	19	08.23	08.30	7	51	45	293	293
3	20	08.30	08.38	8	57	63	292	292
3	21	08.38	08.45	7	50	53	319	319
3	22	08.45	08.53	8	15	16	113	113
3	23	08.53	09.00	7	51	54	295	295
4	24	09.00	09.08	8	31	35	165	165
4	25	09.08	09.15	7	45	44	282	282
4	26	09.15	09.23	8	52	62	261	261
4	27	09.23	09.30	7	47	55	277	277
4	28	09.30	09.38	8	64	72	258	258
4	29	09.38	09.45	7	21	21	191	191
4	30	09.45	09.53	8	83	66	335	335
4	31	09.53	10.00	7	57	61	344	344
5	32	10.00	10.01	1	8	8	50	50
5	33	10.01	10.06	5	18	18	113	113
5	34	10.06	10.08	2	4	4	25	25
5	35	10.08	10.16	8	91	91	488	488

5	36	10.16	10.24	8	57	57	229	229
5	37	10.24	10.32	8	33	33	244	244
5	38	10.32	10.40	8	81	81	342	342
5	39	10.40	10.48	8	26	26	221	221
5	40	10.48	10.56	8	47	47	229	229
5	41	10.56	11.00	4	27	27	208	208
6	42	11.00	11.03	3	21	28	159	159
6	43	11.03	11.11	8	27	29	139	139
6	44	11.11	11.18	7	36	56	304	304
6	45	11.18	11.26	8	68	68	308	308
6	46	11.26	11.33	7	25	26	205	205
6	47	11.33	11.41	8	27	25	145	145
6	48	11.41	11.48	7	57	47	272	272
6	49	11.48	11.56	8	50	52	245	245
6	50	11.56	12.00	4	23	21	205	205
7	51	12.00	12.04	4	23	23	202	202
7	52	12.04	12.11	7	31	31	132	132
7	53	12.11	12.18	7	36	36	250	250
7	54	12.18	12.26	8	20	20	120	120
7	55	12.26	12.34	8	81	81	393	393
7	56	12.34	12.41	7	32	32	201	201
7	57	12.41	12.48	7	42	42	251	251
7	58	12.48	12.56	8	53	53	331	331
7	59	12.56	13.00	4	22	22	132	132
8	60	13.00	13.04	4	23	24	135	135
8	61	13.04	13.11	7	43	50	258	258
8	62	13.11	13.18	7	81	71	449	449
8	63	13.18	13.26	8	67	73	347	347
8	64	13.26	13.34	8	51	82	385	385
8	65	13.34	13.41	7	14	13	90	90
8	66	13.41	13.49	8	21	26	152	152
8	67	13.49	13.57	8	60	50	219	219
8	68	13.57	14.00	3	18	19	57	57
9	69	14.00	14.02	2	12	15	38	38
9	70	14.02	14.07	5	49	49	285	285
9	71	14.07	14.10	3	67	68	296	296
9	72	14.10	14.14	4	41	47	183	183
9	73	14.14	14.21	7	71	70	476	476
9	74	14.21	14.29	8	54	54	268	268
9	75	14.29	14.37	8	50	50	272	272
9	76	14.37	14.44	7	18	17	147	147
9	77	14.44	14.51	7	63	63	429	429
9	78	14.51	14.59	8	40	40	210	210
9	79	14.59	15.00	1	20	20	64	64
10	80	15.00	15.01	1	20	20	65	65
10	81	15.01	15.03	2	60	60	221	221
10	82	15.03	15.06	3	54	54	326	326
10	83	15.06	15.10	4	61	61	224	224
10	84	15.10	15.13	3	26	26	124	124
10	85	15.13	15.19	6	69	69	379	379
10	86	15.19	15.25	6	40	40	194	194
10	87	15.25	15.32	7	48	48	309	309
10	88	15.32	15.40	8	45	45	257	257
10	89	15.40	15.47	7	47	47	427	427
10	90	15.47	15.54	7	58	58	263	263

10	91	15.54	16.00	6	37	37	260	260
11	92	16.00	16.01	1	6	5	43	43
11	93	16.01	16.09	8	33	35	213	213
11	94	16.09	16.16	7	29	33	278	278
11	95	16.16	16.23	7	20	16	156	156
11	96	16.23	16.31	8	73	78	500	500
11	97	16.31	16.39	8	13	10	79	79
11	98	16.39	16.45	6	33	40	297	297
11	99	16.45	16.53	8	27	23	161	161
11	100	16.53	17.00	7	37	38	279	279
12	101	17.00	17.01	1	5	6	41	41
12	102	17.01	17.08	7	17	18	129	129
12	103	17.08	17.15	7	45	45	255	255
12	104	17.15	17.23	8	25	24	180	180
12	105	17.23	17.30	7	19	26	216	216
12	106	17.30	17.38	8	35	25	172	172
12	107	17.38	17.45	7	14	16	177	177
12	108	17.45	17.53	8	17	21	125	125
12	109	17.53	18.00	7	12	16	124	124
13	110	18.00	18.01	1	1	3	17	17
13	111	18.01	18.08	7	23	18	143	143
13	112	18.08	18.13	5	24	29	221	221
13	113	18.13	18.21	8	11	10	71	71
13	114	18.21	18.30	9	29	32	218	218
13	115	18.30	18.40	10	30	37	245	245
13	116	18.40	18.50	10	4	3	54	54
13	117	18.50	19.00	10	6	5	70	70
14	118	19.00	19.10	10	24	24	171	171
14	119	19.10	19.20	10	11	7	55	55
14	120	19.20	19.28	8	11	9	77	77
14	121	19.28	19.41	13	4	12	78	78
14	122	19.41	19.56	15	10	13	95	95
14	123	19.56	20.00	4	4	5	38	38
15	124	20.00	20.11	11	13	11	107	107
15	125	20.11	20.26	15	9	12	96	96
15	126	20.26	20.41	15	6	22	107	107
15	127	20.41	20.56	15	7	9	65	65
15	128	20.56	21.00	4	2	1	12	12
16	129	21.00	21.16	16	8	5	59	59
16	130	21.16	21.36	20	12	13	131	131
16	131	21.36	21.58	22	16	24	162	162
16	132	21.58	22.00	2	0	1	9	9
17	133	22.00	22.28	28	12	14	102	102
17	134	22.28	22.58	30	6	8	73	73
17	135	22.58	23.00	2	1	2	11	11
18	136	23.00	23.28	28	17	22	154	154
18	137	23.28	23.58	30	6	8	71	71
18	138	23.58	24.00	2	0	1	4	4
19	139	24.00	24.28	28	7	7	79	79
19	140	24.28	24.58	30	7	7	37	37
19	141	24.58	25.00	2	0	0	0	0

## Appendix C: Data for RIDCHK (Ride Check) Program

---

The data files read by the RIDCHK program are listed below, along with the contents of the user-prepared file(s). An example of the parameter file prepared for route 217 (southbound) follows.

```

C      103   I   BUS STOP NAMES (SCRTD'S 'STOP' FILE)
C      104   I   BUS STOP DISTANCES AND BRANCH DEFINITIONS
C              (SCRTD'S 'ROUT' FILE)
C      105   I   RUN PARAMETERS
C              CARD IMAGE FILE
C              A. PARAMETER NAMELIST
C                  IRC      I   LOGICAL UNIT FOR READING RIDE
C                              CHECK DATA (DEFAULT=8)
C                  RTENUM   I   ROUTE NUMBER
C                  DIRECT   I   DIRECTION CODE
C                  OPTION   I   OUTPUT FILE OPTION:
C                              1 = 'METHODS' FILE ONLY (DEF)
C                              2 = BOTH FILES
C                  LOADT    I   MAX. LOAD POINT SWITCH
C                              1 = ANY POINT COUNTS (DEF.)
C                              2 = ONLY TIME POINTS COUNT
C                  NMETH    I   NUMBER OF FREQUENCY CALCULA-
C                              TION METHODS (VALUE = 1 - 4,
C                              DEFAULT=4)
C                  BETA4    R   FRACTION OF ROUTE LENGTH
C                              OPERATED ABOVE DESIGN LOAD
C                              IN METHOD FOUR (DEF. = .3)
C                  NAME     I   STOP NAMES TO USE
C                              1 = STOP NUMBER (DEF.)
C                              2 = STOP NAME
C                  SMOOTH   I   SWITCH TO SMOOTH LOADS
C                              BETWEEN PERIODS:
C                              0 = NO
C                              1 = YES (DEFAULT)
C              B. PERIOD NAMELIST
C                  BUSTYP   C   BUS TYPE, 4 CHARACTERS IN
C                              QUOTES
C                  BUSCAP   I   BUS CAPACITY INCL. STANDEES
C                  BEGDAY   I   START OF FIRST PERIOD (HH:MM)
C                              IN 24-HOUR CLOCK
C                  DATA FOR UP TO 20 TIME PERIODS:
C                  TIMINT   I   END-TIME IN 24-HOUR CLOCK
C                              (HH:MM)
C                  DSNLDD   I   DESIGN LOAD
C                  RTTIME   I   ROUND TRIP TIME IN MINUTES
C                  MINFRQ   I   MINIMUM FREQUENCY
C              C. ROUTE NAMELIST (ONLY IF IRC=9):
C                  DATA FOR UP TO 80 STOPS:
C                  STOPS    I   STOP NUMBER
C                  LNKDST   R   DISTANCE TO NEXT STOP
C                              IN MILES

```

```

C      106    0    RUN REPORT
C      108    1    RIDE CHECK DATA (SCRTO'S 'DATA' FILE)
C      109    1    RIDE CHECK DATA IN OPTIONAL FORMAT

C      A. ONE SET OF RECORDS FOR EACH BUS TRIP IN
C      SCHEDULE ORDER; EACH SET CONTAINS ONE
C      RECORD FOR EACH BUS STOP, AS FOLLOWS:
C      CC  1-4    I4    ROUTE NUMBER
C      5-6    I2    DIRECTION CODE
C      17-20   I4    STOP NUMBER
C      24-27   I4    SCHEDULE TIME OF TRIP IN
C      24-HOUR CLOCK (HH:MM)
C      28-32   I5    NUMBER OF BOARDINGS
C      33-37   I5    NUMBER OF ALIGHTINGS

C      109    0    TEMPORARY STORAGE OF RIDE CHECK DATA IF SCRTO
C      FILE IS USED AS INPUT (RECFM=FB, LRECL=40)
C      111    0    FILE FOR 'METHODS' PROGRAM (RECFM=FB, LRECL=124)
C      112    0    FILE FOR 'BUSTIME' PROGRAM (RECFM=FB, LRECL=48)

```

```

&PARAM NMETH=4,BETA4=.2,IRC=8,RTENUM=217,DIRECT=3,NAME=2,
LOADT=0,OPTION=2,SMOOTH=1 &END
&PERIOD BEGDAY=0600,TIMINT=0700,0800,0900,1000,1100,1200,1300,1400,
1500,1600,1700,1800,1900,2000,2100,2200,2300,2400,2500,
BUSTYP='STI.',BUSCAP=80,ISNLOD=60,2*70,60,5*50,60,2*70,2*60,5*50,
RTTIME=77,3*96,3*108,2*118,4*114,6*98,
MINFRQ=19*2 &END

```

***Appendix D:***

***Twenty-two Computer Generated Timetables at the  
Daily Max Load Point of SCRTD Line 217***

***(Complementary to Tables 21-30 for the 32  
Computer Runs Which Appears in Table 20)***

---

Computer Generated Timetable of Line 217  
at the Fairfax/Rosewood Stop

TYPE OF HEADWAYS :EQUAL (1)

TYPE OF TIMETABLE:ONE METHOD (1)

METHOD NUMBER: 1 FROM INTERVAL: 1 TO INTERVAL: 19

CLOCK HEADWAYS: NO (0)

TIMETABLE

\*\*\*\*\*

DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME
1	6.00	43	14.06
2	6.30	44	14.14
3	7.00	45	14.22
4	7.12	46	14.30
5	7.23	47	14.39
6	7.35	48	14.47
7	7.46	49	14.55
8	7.57	50	15.03
9	8.10	51	15.12
10	8.23	52	15.21
11	8.36	53	15.29
12	8.49	54	15.38
13	9.02	55	15.47
14	9.17	56	15.56
15	9.32	57	16.04
16	9.47	58	16.13
17	10.01	59	16.22
18	10.12	60	16.31
19	10.22	61	16.40
20	10.33	62	16.48
21	10.43	63	16.57
22	10.54	64	17.08
23	11.04	65	17.19
24	11.14	66	17.31
25	11.25	67	17.42
26	11.35	68	17.53
27	11.45	69	18.07
28	11.56	70	18.24
29	12.06	71	18.41
30	12.15	72	18.58
31	12.24	73	19.27
32	12.33	74	19.57
33	12.43	75	20.28
34	12.52	76	20.58
35	13.01	77	21.28
36	13.09	78	21.58
37	13.17	79	22.29
38	13.25	80	22.59
39	13.33	81	23.29
40	13.41	82	24.00
41	13.49	83	0.30
42	13.57	84	1.00

COMPARISON MEASURES

\*\*\*\*\*

TOTAL NUMBER OF DEPARTURES: 84  
MINIMUM SINGLE ROUTE (ROUND TRIP) REQUIRED FLEET SIZE 15



Computer Generated Timetable of Line 217  
at the Fairfax/Rosewood Stop

TYPE OF HEADWAYS :EQUAL (1)

TYPE OF TIMETABLE:ONE METHOD (1)

METHOD NUMBER: 3 FROM INTERVAL: 1 TO INTERVAL: 19

CLOCK HEADWAYS: NO (0)

TIMETABLE

\*\*\*\*\*

DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME
1	6.00	34	14.25
2	6.30	35	14.38
3	7.00	36	14.51
4	7.13	37	15.04
5	7.25	38	15.15
6	7.37	39	15.27
7	7.49	40	15.38
8	8.01	41	15.49
9	8.14	42	16.01
10	8.28	43	16.11
11	8.41	44	16.21
12	8.54	45	16.31
13	9.11	46	16.41
14	9.31	47	16.51
15	9.50	48	17.02
16	10.09	49	17.15
17	10.25	50	17.28
18	10.42	51	17.41
19	10.59	52	17.54
20	11.16	53	18.12
21	11.32	54	18.34
22	11.49	55	18.56
23	12.04	56	19.25
24	12.17	57	19.55
25	12.30	58	20.26
26	12.43	59	20.56
27	12.56	60	21.27
28	13.08	61	21.57
29	13.21	62	22.28
30	13.34	63	22.58
31	13.46	64	23.29
32	13.59	65	23.59
33	14.12	66	0.30
		67	1.00

COMPARISON MEASURES

\*\*\*\*\*

TOTAL NUMBER OF DEPARTURES: 67

MINIMUM SINGLE ROUTE (ROUND TRIP) REQUIRED FLEET SIZE 11

Computer Generated Timetable of Line 217  
at the Fairfax/Rosewood Stop

TYPE OF HEADWAYS :EQUAL (1)

TYPE OF TIMETABLE COMBINATION OF METHODS 5  
 METHOD NUMBER: 2 FROM INTERVAL: 1 TO INTERVAL: 1  
 METHOD NUMBER: 4 FROM INTERVAL: 2 TO INTERVAL: 3  
 METHOD NUMBER: 2 FROM INTERVAL: 4 TO INTERVAL: 11  
 METHOD NUMBER: 4 FROM INTERVAL: 12 TO INTERVAL: 13  
 METHOD NUMBER: 2 FROM INTERVAL: 14 TO INTERVAL: 19

CLOCK HEADWAYS: NO (0)

TIMETABLE

\*\*\*\*\*

DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME
1	6.00	43	13.55
2	6.30	44	14.03
3	7.00	45	14.11
4	7.12	46	14.19
5	7.24	47	14.27
6	7.36	48	14.35
7	7.47	49	14.43
8	7.59	50	14.51
9	8.12	51	15.00
10	8.25	52	15.08
11	8.38	53	15.16
12	8.50	54	15.25
13	9.04	55	15.33
14	9.18	56	15.42
15	9.33	57	15.50
16	9.48	58	15.59
17	10.02	59	16.08
18	10.12	60	16.16
19	10.22	61	16.25
20	10.33	62	16.34
21	10.43	63	16.43
22	10.54	64	16.51
23	11.04	65	17.00
24	11.14	66	17.13
25	11.25	67	17.25
26	11.35	68	17.37
27	11.45	69	17.50
28	11.56	70	18.03
29	12.05	71	18.22
30	12.12	72	18.40
31	12.20	73	18.59
32	12.28	74	19.28
33	12.36	75	19.58
34	12.44	76	20.28
35	12.52	77	20.59
36	13.00	78	21.29
37	13.08	79	21.59
38	13.16	80	22.29
39	13.24	81	22.59
40	13.31	82	23.29
41	13.39	83	24.00
42	13.47	84	0.30
		85	1.00

COMPARISON MEASURES  
\*\*\*\*\*

TOTAL NUMBER OF DEPARTURES: 85  
 MINIMUM SINGLE ROUTE (ROUND TRIP) REQUIRED FLEET SIZE 15

Computer Generated Timetable of Line 217  
at the Fairfax/Rosewood Stop

TYPE OF HEADWAYS :EQUAL (1)

TYPE OF TIMETABLE:ONE METHOD (1)

METHOD NUMBER: 4 FROM INTERVAL: 1 TO INTERVAL: 19

CLOCK HEADWAYS :YES (1)

TIMETABLE

\*\*\*\*\*

DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME
1	6.00	40	14.00
2	6.30	41	14.10
3	7.00	42	14.20
4	7.12	43	14.30
5	7.24	44	14.40
6	7.36	45	14.50
7	7.48	46	15.00
8	8.00	47	15.10
9	8.12	48	15.20
10	8.24	49	15.30
11	8.36	50	15.40
12	8.48	51	15.50
13	9.00	52	16.00
14	9.20	53	16.10
15	9.40	54	16.20
16	10.00	55	16.30
17	10.12	56	16.40
18	10.24	57	16.50
19	10.36	58	17.00
20	10.48	59	17.12
21	11.00	60	17.24
22	11.12	61	17.36
23	11.24	62	17.48
24	11.36	63	18.00
25	11.48	64	18.20
26	12.00	65	18.40
27	12.10	66	19.00
28	12.20	67	19.30
29	12.30	68	20.00
30	12.40	69	20.30
31	12.50	70	21.00
32	13.00	71	21.30
33	13.07	72	22.00
34	13.15	73	22.30
35	13.22	74	23.00
36	13.30	75	23.30
37	13.37	76	24.00
38	13.45	77	0.30
39	13.52	78	1.00

COMPARISON MEASURES

\*\*\*\*\*

TOTAL NUMBER OF DEPARTURES: 78  
MINIMUM SINGLE ROUTE (ROUND TRIP) REQUIRED FLEET SIZE 14

Computer Generated Timetable of Line 217  
at the Fairfax/Rosewood Stop

TYPE OF HEADWAYS :EQUAL (1)

TYPE OF TIMETABLE:ONE METHOD (1)

METHOD NUMBER: 2 FROM INTERVAL: 1 TO INTERVAL: 19

CLOCK HEADWAYS: ND (0), Prespecified number of departures: 70

TIMETABLE

\*\*\*\*\*

DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME
1	6.00	36	13.59
2	6.38	37	14.09
3	7.05	38	14.19
4	7.18	39	14.29
5	7.32	40	14.39
6	7.45	41	14.49
7	7.58	42	14.59
8	8.12	43	15.10
9	8.26	44	15.20
10	8.40	45	15.31
11	8.55	46	15.42
12	9.12	47	15.52
13	9.30	48	16.03
14	9.48	49	16.14
15	10.05	50	16.25
16	10.18	51	16.36
17	10.31	52	16.47
18	10.43	53	16.58
19	10.56	54	17.11
20	11.09	55	17.25
21	11.22	56	17.39
22	11.35	57	17.53
23	11.48	58	18.10
24	12.01	59	18.30
25	12.11	60	18.51
26	12.20	61	19.21
27	12.30	62	19.59
28	12.40	63	20.36
29	12.50	64	21.14
30	13.00	65	21.52
31	13.10	66	22.29
32	13.20	67	23.07
33	13.29	68	23.45
34	13.39	69	0.22
35	13.49	70	1.00

COMPARISON MEASURES

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TOTAL NUMBER OF DEPARTURES: 70  
MINIMUM SINGLE ROUTE (ROUND TRIP) REQUIRED FLEET SIZE 12

Computer Generated Timetable of Line 217  
at the Fairfax/Rosewood Stop

TYPE OF HEADWAYS :EQUAL (1)

TYPE OF TIMETABLE:ONE METHOD (1)

METHOD NUMBER: 2 FROM INTERVAL: 1 TO INTERVAL: 19

CLOCK HEADWAYS: NO (0), Prespecified number of departures: 140

TIMETABLE				36	10.48	106	16.59
*****				37	10.55	107	17.06
DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME	38	11.01	108	17.12
1	6.00	71	13.56	39	11.08	109	17.19
2	6.19	72	14.01	40	11.14	110	17.26
3	6.37	73	14.06	41	11.20	111	17.33
4	6.56	74	14.11	42	11.27	112	17.40
5	7.05	75	14.16	43	11.33	113	17.47
6	7.12	76	14.21	44	11.40	114	17.54
7	7.18	77	14.26	45	11.46	115	18.02
8	7.25	78	14.31	46	11.52	116	18.12
9	7.31	79	14.36	47	11.59	117	18.22
10	7.38	80	14.41	48	12.04	118	18.32
11	7.44	81	14.46	49	12.09	119	18.42
12	7.51	82	14.51	50	12.14	120	18.52
13	7.57	83	14.56	51	12.19	121	19.05
14	8.04	84	15.01	52	12.24	122	19.24
15	8.11	85	15.07	53	12.29	123	19.42
16	8.18	86	15.12	54	12.33	124	20.01
17	8.25	87	15.17	55	12.38	125	20.20
18	8.32	88	15.22	56	12.43	126	20.38
19	8.40	89	15.28	57	12.48	127	20.57
20	8.47	90	15.33	58	12.53	128	21.16
21	8.54	91	15.38	59	12.58	129	21.34
22	9.01	92	15.43	60	13.03	130	21.53
23	9.10	93	15.49	61	13.08	131	22.12
24	9.19	94	15.54	62	13.13	132	22.30
25	9.28	95	15.59	63	13.17	133	22.49
26	9.37	96	16.04	64	13.22	134	23.08
27	9.47	97	16.10	65	13.27	135	23.27
28	9.56	98	16.15	66	13.32	136	23.45
29	10.03	99	16.21	67	13.37	137	0.04
30	10.10	100	16.26	68	13.42	138	0.23
31	10.16	101	16.32	69	13.47	139	0.41
32	10.23	102	16.37	70	13.51	140	1.00
33	10.29	103	16.43				
34	10.35	104	16.48				
35	10.42	105	16.53				

COMPARISON MEASURES

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TOTAL NUMBER OF DEPARTURES: 140  
MINIMUM SINGLE ROUTE (ROUND TRIP) REQUIRED FLEET SIZE 24

Computer Generated Timetable of Line 217  
at the Fairfax/Rosewood Stop

TYPE OF HEADWAYS : BALANCED (2)

TYPE OF TIMETABLE: ONE METHOD (1)

METHOD NUMBER: 1 FROM INTERVAL: 1 TO INTERVAL: 19

CLOCK HEADWAYS: NO (0)

TIMETABLE

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DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME
1	6.00	43	14.04
2	6.36	44	14.10
3	7.01	45	14.18
4	7.23	46	14.31
5	7.37	47	14.37
6	7.45	48	14.48
7	7.52	49	14.56
8	7.58	50	15.05
9	8.07	51	15.15
10	8.19	52	15.22
11	8.36	53	15.34
12	8.46	54	15.40
13	9.01	55	15.47
14	9.12	56	15.57
15	9.26	57	16.04
16	9.41	58	16.12
17	10.01	59	16.24
18	10.14	60	16.31
19	10.26	61	16.42
20	10.36	62	16.47
21	10.46	63	16.58
22	10.55	64	17.07
23	11.07	65	17.18
24	11.14	66	17.24
25	11.21	67	17.42
26	11.34	68	17.54
27	11.45	69	18.11
28	11.56	70	18.24
29	12.05	71	18.40
30	12.13	72	18.56
31	12.25	73	19.28
32	12.32	74	19.58
33	12.40	75	20.23
34	12.49	76	20.58
35	13.01	77	21.23
36	13.05	78	21.58
37	13.11	79	22.26
38	13.21	80	22.58
39	13.28	81	23.17
40	13.38	82	23.59
41	13.50	83	0.21
42	13.57	84	1.00

COMPARISON MEASURES

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TOTAL NUMBER OF DEPARTURES: 84  
MINIMUM SINGLE ROUTE (ROUND TRIP) REQUIRED FLEET SIZE 15

Computer Generated Timetable of Line 217  
at the Fairfax/Rosewood Stop

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

TYPE OF TIMETABLE: ONE METHOD (1)

METHOD NUMBER: 3 FROM INTERVAL: 1 TO INTERVAL: 19

CLOCK HEADWAYS: NO (0)

TIMETABLE

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DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME
1	6.00	34	14.26
2	6.36	35	14.37
3	7.03	36	14.52
4	7.21	37	15.04
5	7.36	38	15.16
6	7.44	39	15.24
7	7.52	40	15.36
8	8.01	41	15.46
9	8.08	42	16.01
10	8.19	43	16.10
11	8.35	44	16.24
12	8.47	45	16.32
13	9.06	46	16.44
14	9.23	47	16.53
15	9.46	48	17.01
16	10.07	49	17.14
17	10.27	50	17.24
18	10.43	51	17.41
19	10.59	52	17.56
20	11.14	53	18.13
21	11.32	54	18.33
22	11.48	55	18.54
23	12.04	56	19.25
24	12.15	57	19.56
25	12.31	58	20.18
26	12.39	59	20.57
27	12.52	60	21.25
28	13.05	61	21.57
29	13.16	62	22.26
30	13.30	63	22.58
31	13.47	64	23.15
32	13.59	65	23.59
33	14.08	66	0.12
		67	1.00

COMPARISON MEASURES

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TOTAL NUMBER OF DEPARTURES: 67  
MINIMUM SINGLE ROUTE (ROUND TRIP) REQUIRED FLEET SIZE 11

Computer Generated Timetable of Line 217  
at the Fairfax/Rosewood Stop

TYPE OF HEADWAYS : BALANCED (2)

TYPE OF TIMETABLE COMBINATION OF METHODS 5

METHOD NUMBER: 2 FROM INTERVAL: 1 TO INTERVAL: 1  
 METHOD NUMBER: 4 FROM INTERVAL: 2 TO INTERVAL: 3  
 METHOD NUMBER: 2 FROM INTERVAL: 4 TO INTERVAL: 11  
 METHOD NUMBER: 4 FROM INTERVAL: 12 TO INTERVAL: 13  
 METHOD NUMBER: 2 FROM INTERVAL: 14 TO INTERVAL: 19

CLOCK HEADWAYS: NO (0)

TIMETABLE

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DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME
1	6.00	43	13.54
2	6.38	44	14.02
3	7.01	45	14.09
4	7.21	46	14.17
5	7.35	47	14.30
6	7.43	48	14.36
7	7.52	49	14.46
8	8.00	50	14.54
9	8.07	51	15.00
10	8.16	52	15.11
11	8.33	53	15.16
12	8.43	54	15.24
13	9.02	55	15.35
14	9.14	56	15.41
15	9.27	57	15.50
16	9.43	58	15.59
17	10.02	59	16.06
18	10.15	60	16.16
19	10.27	61	16.27
20	10.36	62	16.33
21	10.46	63	16.44
22	10.55	64	16.50
23	11.07	65	17.00
24	11.14	66	17.11
25	11.21	67	17.22
26	11.34	68	17.35
27	11.45	69	17.53
28	11.56	70	18.07
29	12.03	71	18.20
30	12.08	72	18.38
31	12.16	73	18.58
32	12.26	74	19.29
33	12.34	75	19.58
34	12.41	76	20.23
35	12.50	77	20.59
36	13.00	78	21.35
37	13.05	79	21.58
38	13.11	80	22.27
39	13.18	81	22.59
40	13.26	82	23.17
41	13.35	83	24.00
42	13.46	84	0.13
		85	1.00

COMPARISON MEASURES

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TOTAL NUMBER OF DEPARTURES: 85  
 MINIMUM SINGLE ROUTE (ROUND TRIP) REQUIRED FLEET SIZE 15



Computer Generated Timetable of Line 217  
at the Fairfax/Rosewood Stop

TYPE OF HEADWAYS : BALANCED (2)

TYPE OF TIMETABLE: ONE METHOD (1)

METHOD NUMBER: 2 FROM INTERVAL: 1 TO INTERVAL: 19

CLOCK HEADWAYS: NO (0), Prespecified number of departures: 70

TIMETABLE

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DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME
1	6.00	36	13.58
2	6.49	37	14.07
3	7.13	38	14.16
4	7.32	39	14.31
5	7.42	40	14.39
6	7.51	41	14.52
7	7.59	42	15.00
8	8.08	43	15.15
9	8.21	44	15.19
10	8.38	45	15.33
11	8.50	46	15.41
12	9.06	47	15.53
13	9.24	48	16.02
14	9.44	49	16.12
15	10.04	50	16.27
16	10.20	51	16.35
17	10.34	52	16.46
18	10.46	53	16.58
19	10.57	54	17.10
20	11.11	55	17.21
21	11.19	56	17.36
22	11.34	57	17.54
23	11.48	58	18.12
24	12.01	59	18.30
25	12.07	60	18.49
26	12.16	61	19.21
27	12.28	62	19.59
28	12.37	63	20.30
29	12.48	64	21.18
30	13.00	65	21.51
31	13.06	66	22.27
32	13.14	67	23.04
33	13.24	68	23.38
34	13.35	69	0.09
35	13.48	70	1.00

COMPARISON MEASURES

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TOTAL NUMBER OF DEPARTURES: 70  
MINIMUM SINGLE ROUTE (ROUND TRIP) REQUIRED FLEET SIZE 12

Computer Generated Timetable of Line 217  
at the Fairfax/Rosewood Stop

TYPE OF HEADWAYS : BALANCED (2)

TYPE OF TIMETABLE: ONE METHOD (1)

METHOD NUMBER: 2 FROM INTERVAL: 1 TO INTERVAL: 19

CLOCK HEADWAYS: NO (0), Prespecified number of departures: 140

TIMETABLE

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DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME	DEPARTURE NUMBER	TIME	DEPARTURE NUMBER	TIME
1	6.00	71	13.55	36	10.51	106	16.59
2	6.32	72	14.01	37	10.56	107	17.04
3	6.49	73	14.05	38	11.02	108	17.12
4	6.55	74	14.09	39	11.10	109	17.18
5	7.12	75	14.14	40	11.14	110	17.22
6	7.24	76	14.23	41	11.18	111	17.28
7	7.31	77	14.29	42	11.22	112	17.39
8	7.38	78	14.33	43	11.32	113	17.48
9	7.42	79	14.36	44	11.39	114	17.55
10	7.47	80	14.41	45	11.46	115	18.03
11	7.51	81	14.49	46	11.53	116	18.13
12	7.55	82	14.54	47	11.59	117	18.20
13	7.58	83	14.57	48	12.03	118	18.31
14	8.03	84	15.01	49	12.06	119	18.41
15	8.07	85	15.08	50	12.09	120	18.51
16	8.12	86	15.15	51	12.14	121	19.06
17	8.19	87	15.16	52	12.21	122	19.24
18	8.31	88	15.21	53	12.27	123	19.44
19	8.37	89	15.29	54	12.31	124	20.01
20	8.42	90	15.34	55	12.35	125	20.15
21	8.49	91	15.38	56	12.40	126	20.32
22	9.01	92	15.42	57	12.46	127	20.57
23	9.06	93	15.47	58	12.51	128	21.20
24	9.15	94	15.54	59	12.57	129	21.39
25	9.23	95	15.59	60	13.02	130	21.52
26	9.32	96	16.04	61	13.05	131	22.11
27	9.41	97	16.08	62	13.08	132	22.28
28	9.55	98	16.14	63	13.12	133	22.45
29	10.03	99	16.23	64	13.16	134	23.04
30	10.11	100	16.28	65	13.21	135	23.14
31	10.19	101	16.32	66	13.27	136	23.39
32	10.27	102	16.37	67	13.32	137	0.02
33	10.33	103	16.44	68	13.38	138	0.09
34	10.38	104	16.47	69	13.45	139	0.32
35	10.44	105	16.53	70	13.50	140	1.00

COMPARISON MEASURES  
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TOTAL NUMBER OF DEPARTURES: 140  
MINIMUM SINGLE ROUTE (ROUND TRIP) REQUIRED FLFET SIZE 24

Computer Generated Timetable of Line 217  
at the Fairfax/Beverly Stop

TYPE OF HEADWAYS :EQUAL (1)

TYPE OF TIMETABLE:ONE METHOD (1)

METHOD NUMBER: 1 FROM INTERVAL: 1 TO INTERVAL: 19

CLOCK HEADWAYS: NO (0)

TIMETABLE

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DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME
1	6.00	45	13.30
2	6.25	46	13.38
3	6.51	47	13.46
4	7.08	48	13.55
5	7.21	49	14.02
6	7.34	50	14.08
7	7.47	51	14.15
8	8.00	52	14.21
9	8.11	53	14.27
10	8.21	54	14.33
11	8.32	55	14.40
12	8.43	56	14.46
13	8.54	57	14.52
14	9.04	58	14.58
15	9.13	59	15.05
16	9.22	60	15.11
17	9.31	61	15.18
18	9.40	62	15.24
19	9.49	63	15.31
20	9.58	64	15.37
21	10.06	65	15.43
22	10.14	66	15.50
23	10.22	67	15.56
24	10.30	68	16.07
25	10.37	69	16.23
26	10.45	70	16.38
27	10.53	71	16.54
28	11.01	72	17.14
29	11.10	73	17.36
30	11.19	74	17.59
31	11.28	75	18.27
32	11.37	76	18.56
33	11.46	77	19.26
34	11.55	78	19.56
35	12.04	79	20.27
36	12.13	80	20.57
37	12.22	81	21.27
38	12.31	82	21.58
39	12.40	83	22.28
40	12.49	84	22.58
41	12.58	85	23.29
42	13.06	86	23.59
43	13.14	87	0.30
44	13.22	88	1.00

COMPARISON MEASURES

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TOTAL NUMBER OF DEPARTURES: 88  
MINIMUM SINGLE ROUTE (ROUND TRIP) REQUIRED FLEET SIZE 19

Computer Generated Timetable of Line 217  
at the Fairfax/Beverly Stop

TYPE OF HEADWAYS :EQUAL (1)

TYPE OF TIMETABLE:ONE METHOD (1)

METHOD NUMBER: 3 FROM INTERVAL: 1 TO INTERVAL: 19

CLOCK HEADWAYS: NO (0)

TIMETABLE

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DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME
1	6.00	35	13.45
2	6.30	36	13.57
3	7.00	37	14.08
4	7.13	38	14.18
5	7.26	39	14.27
6	7.40	40	14.37
7	7.53	41	14.47
8	8.05	42	14.57
9	8.17	43	15.06
10	8.29	44	15.15
11	8.41	45	15.23
12	8.52	46	15.32
13	9.04	47	15.40
14	9.16	48	15.49
15	9.28	49	15.57
16	9.39	50	16.12
17	9.51	51	16.30
18	10.03	52	16.47
19	10.15	53	17.07
20	10.27	54	17.31
21	10.40	55	17.56
22	10.52	56	18.26
23	11.05	57	18.56
24	11.19	58	19.26
25	11.33	59	19.57
26	11.47	60	20.27
27	12.00	61	20.57
28	12.15	62	21.28
29	12.29	63	21.58
30	12.43	64	22.28
31	12.57	65	22.59
32	13.10	66	23.29
33	13.22	67	23.59
34	13.34	68	0.30
		69	1.00

COMPARISON MEASURES

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TOTAL NUMBER OF DEPARTURES: 69  
MINIMUM SINGLE ROUTE (ROUND TRIP) REQUIRED FLEET SIZE 13

Computer Generated Timetable of Line 217  
at the Fairfax/Beverly Stop

TYPE OF HEADWAYS :EQUAL (1)

TYPE OF TIMETABLE COMBINATION OF METHODS 5  
 METHOD NUMBER: 2 FROM INTERVAL: 1 TO INTERVAL: 1  
 METHOD NUMBER: 4 FROM INTERVAL: 2 TO INTERVAL: 3  
 METHOD NUMBER: 2 FROM INTERVAL: 4 TO INTERVAL: 11  
 METHOD NUMBER: 4 FROM INTERVAL: 12 TO INTERVAL: 13  
 METHOD NUMBER: 2 FROM INTERVAL: 14 TO INTERVAL: 19

CLOCK HEADWAYS: NO (0)

TIMETABLE

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DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME
1	6.00	45	13.26
2	6.25	46	13.33
3	6.49	47	13.40
4	7.07	48	13.48
5	7.20	49	13.55
6	7.33	50	14.02
7	7.46	51	14.08
8	7.59	52	14.14
9	8.10	53	14.21
10	8.22	54	14.27
11	8.34	55	14.33
12	8.46	56	14.39
13	8.58	57	14.45
14	9.07	58	14.51
15	9.16	59	14.57
16	9.24	60	15.04
17	9.33	61	15.10
18	9.42	62	15.17
19	9.51	63	15.23
20	9.59	64	15.29
21	10.07	65	15.36
22	10.15	66	15.42
23	10.23	67	15.49
24	10.30	68	15.55
25	10.38	69	16.04
26	10.46	70	16.19
27	10.54	71	16.34
28	11.01	72	16.50
29	11.10	73	17.08
30	11.19	74	17.32
31	11.27	75	17.57
32	11.36	76	18.26
33	11.44	77	18.57
34	11.53	78	19.27
35	12.02	79	19.57
36	12.11	80	20.28
37	12.19	81	20.58
38	12.28	82	21.28
39	12.37	83	21.58
40	12.46	84	22.29
41	12.55	85	22.59
42	13.03	86	23.29
43	13.11	87	24.00
44	13.18	88	0.30
		89	1.00

COMPARISON MEASURES  
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TOTAL NUMBER OF DEPARTURES: 89  
 MINIMUM SINGLE ROUTE (ROUND TRIP) REQUIRED FLEET SIZE 19

Computer Generated Timetable of Line 217  
at the Fairfax/Beverly Stop

TYPE OF HEADWAYS :EQUAL (1)

TYPE OF TIMETABLE:ONE METHOD (1)

METHOD NUMBER: 4 FROM INTERVAL: 1 TO INTERVAL: 19

CLOCK HEADWAYS :YES (1)

TIMETABLE

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DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME
1	6.00	38	13.30
2	6.30	39	13.40
3	7.00	40	13.50
4	7.12	41	14.00
5	7.24	42	14.10
6	7.36	43	14.20
7	7.48	44	14.30
8	8.00	45	14.40
9	8.12	46	14.50
10	8.24	47	15.00
11	8.36	48	15.07
12	8.48	49	15.15
13	9.00	50	15.22
14	9.12	51	15.30
15	9.24	52	15.37
16	9.36	53	15.45
17	9.48	54	15.52
18	10.00	55	16.00
19	10.10	56	16.20
20	10.20	57	16.40
21	10.30	58	17.00
22	10.40	59	17.30
23	10.50	60	18.00
24	11.00	61	18.30
25	11.10	62	19.00
26	11.20	63	19.30
27	11.30	64	20.00
28	11.40	65	20.30
29	11.50	66	21.00
30	12.00	67	21.30
31	12.12	68	22.00
32	12.24	69	22.30
33	12.36	70	23.00
34	12.48	71	23.30
35	13.00	72	24.00
36	13.10	73	0.30
37	13.20	74	1.00

COMPARISON MEASURES

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TOTAL NUMBER OF DEPARTURES: 74

MINIMUM SINGLE ROUTE (ROUND TRIP) REQUIRED FLEET SIZE 14

Computer Generated Timetable of Line 217  
at the Fairfax/Beverly Stop

TYPE OF HEADWAYS :EQUAL (1)

TYPE OF TIMETABLE:ONE METHOD (1)

METHOD NUMBER: 2 FROM INTERVAL: 1 TO INTERVAL: 19

CLOCK HEADWAYS: NO (0), Prespecified number of departures: 70

TIMETABLE

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DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME
1	6.00	36	13.28
2	6.32	37	13.38
3	7.02	38	13.47
4	7.17	39	13.57
5	7.32	40	14.05
6	7.47	41	14.13
7	8.01	42	14.21
8	8.15	43	14.29
9	8.28	44	14.37
10	8.42	45	14.45
11	8.55	46	14.53
12	9.07	47	15.02
13	9.19	48	15.10
14	9.30	49	15.18
15	9.42	50	15.27
16	9.53	51	15.35
17	10.04	52	15.43
18	10.14	53	15.52
19	10.24	54	16.00
20	10.34	55	16.20
21	10.44	56	16.40
22	10.54	57	17.00
23	11.05	58	17.28
24	11.16	59	17.56
25	11.27	60	18.30
26	11.38	61	19.05
27	11.49	62	19.44
28	12.01	63	20.24
29	12.12	64	21.03
30	12.24	65	21.43
31	12.36	66	22.22
32	12.47	67	23.02
33	12.59	68	23.41
34	13.09	69	0.21
35	13.18	70	1.00

COMPARISON MEASURES

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TOTAL NUMBER OF DEPARTURES: 70

MINIMUM SINGLE ROUTE (ROUND TRIP) REQUIRED FLEET SIZE 15

Computer Generated Timetable of Line 217  
at the Fairfax/Beverly Stop

TYPE OF HEADWAYS :EQUAL (1)

TYPE OF TIMETABLE:ONE METHOD (1)

METHOD NUMBER: 2 FROM INTERVAL: 1 TO INTERVAL: 19

CLOCK HEADWAYS: NO (0), Prespecified number of departures: 140

TIMETABLE

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DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME		TIME		TIME
1	6.00	71	13.25	36	10.18	106	15.53
2	6.16	72	13.30	37	10.23	107	15.57
3	6.32	73	13.35	38	10.28	108	16.03
4	6.48	74	13.40	39	10.33	109	16.13
5	7.02	75	13.45	40	10.38	110	16.22
6	7.09	76	13.49	41	10.43	111	16.32
7	7.17	77	13.54	42	10.48	112	16.42
8	7.24	78	13.59	43	10.53	113	16.52
9	7.31	79	14.03	44	10.58	114	17.03
10	7.39	80	14.07	45	11.03	115	17.17
11	7.46	81	14.11	46	11.08	116	17.30
12	7.54	82	14.15	47	11.14	117	17.44
13	8.01	83	14.19	48	11.20	118	17.58
14	8.08	84	14.23	49	11.25	119	18.15
15	8.14	85	14.27	50	11.31	120	18.32
16	8.21	86	14.31	51	11.36	121	18.49
17	8.28	87	14.35	52	11.42	122	19.08
18	8.34	88	14.39	53	11.47	123	19.27
19	8.41	89	14.43	54	11.53	124	19.47
20	8.48	90	14.47	55	11.58	125	20.06
21	8.54	91	14.51	56	12.04	126	20.26
22	9.01	92	14.55	57	12.10	127	20.45
23	9.06	93	14.59	58	12.16	128	21.05
24	9.12	94	15.03	59	12.21	129	21.25
25	9.18	95	15.07	60	12.27	130	21.44
26	9.23	96	15.11	61	12.33	131	22.04
27	9.29	97	15.15	62	12.39	132	22.23
28	9.35	98	15.20	63	12.45	133	22.43
29	9.40	99	15.24	64	12.50	134	23.03
30	9.46	100	15.28	65	12.56	135	23.22
31	9.52	101	15.32	66	13.01	136	23.42
32	9.57	102	15.36	67	13.06	137	0.01
33	10.03	103	15.40	68	13.11	138	0.21
34	10.08	104	15.44	69	13.16	139	0.40
35	10.13	105	15.49	70	13.21	140	1.00

COMPARISON MEASURES  
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TOTAL NUMBER OF DEPARTURES: 140  
MINIMUM SINGLE ROUTE (ROUND TRIP) REQUIRED FLEET SIZE 30



Computer Generated Timetable of Line 217  
at the Fairfax/Beverly Stop

TYPE OF HEADWAYS : BALANCED (2)

TYPE OF TIMETABLE: ONE METHOD (1)

METHOD NUMBER: 1 FROM INTERVAL: 1 TO INTERVAL: 19

CLOCK HEADWAYS: NO (0)

TIMETABLE

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DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME
1	6.00	45	13.23
2	6.32	46	13.30
3	6.57	47	13.46
4	7.11	48	13.55
5	7.24	49	14.02
6	7.36	50	14.07
7	7.47	51	14.10
8	8.00	52	14.14
9	8.06	53	14.19
10	8.19	54	14.25
11	8.29	55	14.33
12	8.39	56	14.45
13	8.54	57	14.51
14	9.07	58	14.59
15	9.17	59	15.02
16	9.26	60	15.04
17	9.34	61	15.08
18	9.46	62	15.14
19	9.52	63	15.19
20	9.59	64	15.28
21	10.09	65	15.38
22	10.14	66	15.47
23	10.19	67	15.54
24	10.28	68	16.07
25	10.35	69	16.25
26	10.41	70	16.38
27	10.53	71	16.55
28	11.01	72	17.11
29	11.12	73	17.31
30	11.21	74	17.58
31	11.27	75	18.20
32	11.41	76	18.42
33	11.48	77	19.13
34	11.56	78	19.56
35	12.04	79	20.17
36	12.15	80	20.56
37	12.28	81	21.31
38	12.33	82	21.57
39	12.42	83	22.21
40	12.50	84	22.59
41	12.58	85	23.19
42	13.07	86	23.59
43	13.13	87	0.29
44	13.17	88	0.58

COMPARISON MEASURES

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TOTAL NUMBER OF DEPARTURES: 88  
MINIMUM SINGLE ROUTE (ROUND TRIP) REQUIRED FLEET SIZE 19

Computer Generated Timetable of Line 217  
at the Fairfax/Beverly Stop

TYPE OF HEADWAYS : BALANCED (2)

TYPE OF TIMETABLE: ONE METHOD (1)

METHOD NUMBER: 3 FROM INTERVAL: 1 TO INTERVAL: 19

CLOCK HEADWAYS: NO (0)

TIMETABLE

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DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME
1	6.00	35	13.35
2	6.39	36	13.56
3	7.00	37	14.07
4	7.15	38	14.13
5	7.30	39	14.20
6	7.42	40	14.32
7	7.51	41	14.46
8	8.03	42	14.56
9	8.14	43	15.03
10	8.26	44	15.08
11	8.37	45	15.16
12	8.53	46	15.27
13	9.07	47	15.38
14	9.18	48	15.46
15	9.30	49	15.57
16	9.43	50	16.13
17	9.53	51	16.28
18	10.03	52	16.46
19	10.14	53	17.07
20	10.27	54	17.28
21	10.39	55	17.55
22	10.54	56	18.20
23	11.04	57	18.50
24	11.19	58	19.20
25	11.32	59	19.57
26	11.48	60	20.21
27	12.00	61	20.55
28	12.15	62	21.32
29	12.31	63	21.58
30	12.45	64	22.24
31	12.57	65	22.59
32	13.10	66	23.20
33	13.17	67	23.59
34	13.26	68	0.20
		69	0.58

COMPARISON MEASURES

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TOTAL NUMBER OF DEPARTURES: 69  
MINIMUM SINGLE ROUTE (ROUND TRIP) REQUIRED FLEET SIZE 13

Computer Generated Timetable of Line 217  
at the Fairfax/Beverly Stop

TYPE OF HEADWAYS : BALANCED (2)

TYPE OF TIMETABLE COMBINATION OF METHODS 5

METHOD NUMBER: 2 FROM INTERVAL: 1 TO INTERVAL: 1  
 METHOD NUMBER: 4 FROM INTERVAL: 2 TO INTERVAL: 3  
 METHOD NUMBER: 2 FROM INTERVAL: 4 TO INTERVAL: 11  
 METHOD NUMBER: 4 FROM INTERVAL: 12 TO INTERVAL: 13  
 METHOD NUMBER: 2 FROM INTERVAL: 14 TO INTERVAL: 19

CLOCK HEADWAYS: NO (0)

TIMETABLE

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DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME
1	6.00	45	13.21
2	6.32	46	13.27
3	6.56	47	13.32
4	7.09	48	13.45
5	7.23	49	13.55
6	7.36	50	14.02
7	7.46	51	14.07
8	7.58	52	14.09
9	8.07	53	14.13
10	8.19	54	14.18
11	8.30	55	14.24
12	8.42	56	14.32
13	8.58	57	14.44
14	9.10	58	14.50
15	9.19	59	14.59
16	9.27	60	15.02
17	9.34	61	15.04
18	9.45	62	15.07
19	9.53	63	15.13
20	10.00	64	15.18
21	10.09	65	15.26
22	10.14	66	15.36
23	10.20	67	15.45
24	10.29	68	15.53
25	10.36	69	16.04
26	10.42	70	16.23
27	10.53	71	16.30
28	11.01	72	16.49
29	11.11	73	17.08
30	11.18	74	17.28
31	11.23	75	17.56
32	11.34	76	18.21
33	11.45	77	18.52
34	11.53	78	19.20
35	12.02	79	19.57
36	12.12	80	20.28
37	12.26	81	20.54
38	12.31	82	21.38
39	12.38	83	21.58
40	12.47	84	22.23
41	12.55	85	23.00
42	13.04	86	23.19
43	13.11	87	24.00
44	13.16	88	0.28
		89	0.58

COMPARISON MEASURES

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TOTAL NUMBER OF DEPARTURES: 89

Computer Generated Timetable of Line 217  
at the Fairfax/Rosewood Stop

TYPE OF HEADWAYS : BALANCED (2)

TYPE OF TIMETABLE: ONE METHOD (1)

METHOD NUMBER: 2 FROM INTERVAL: 1 TO INTERVAL: 19

CLOCK HEADWAYS: NO (0), Prespecified number of departures: 70

TIMETABLE

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DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME
1	6.00	36	13.58
2	6.49	37	14.07
3	7.13	38	14.16
4	7.32	39	14.31
5	7.42	40	14.39
6	7.51	41	14.52
7	7.59	42	15.00
8	8.08	43	15.15
9	8.21	44	15.19
10	8.38	45	15.33
11	8.50	46	15.41
12	9.06	47	15.53
13	9.24	48	16.02
14	9.44	49	16.12
15	10.04	50	16.27
16	10.20	51	16.35
17	10.34	52	16.46
18	10.46	53	16.58
19	10.57	54	17.10
20	11.11	55	17.21
21	11.19	56	17.36
22	11.34	57	17.54
23	11.48	58	18.12
24	12.01	59	18.30
25	12.07	60	18.49
26	12.16	61	19.21
27	12.28	62	19.59
28	12.37	63	20.30
29	12.48	64	21.18
30	13.00	65	21.51
31	13.06	66	22.27
32	13.14	67	23.04
33	13.24	68	23.38
34	13.35	69	0.09
35	13.48	70	1.00

COMPARISON MEASURES

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TOTAL NUMBER OF DEPARTURES: 70  
MINIMUM SINGLE ROUTE (ROUND TRIP) REQUIRED FLEET SIZE 12

Computer Generated Timetable of Line 217  
at the Fairfax/Rosewood Stop

TYPE OF HEADWAYS : BALANCED (2)

TYPE OF TIMETABLE: ONE METHOD (1)

METHOD NUMBER: 2 FROM INTERVAL: 1 TO INTERVAL: 19

CLOCK HEADWAYS: NO (0), Prespecified number of departures: 140

TIMETABLE							
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DEPARTURE-NUMBER	TIME	DEPARTURE NUMBER	TIME				
1	6.00	71	13.55	36	10.51	106	16.59
2	6.32	72	14.01	37	10.56	107	17.04
3	6.49	73	14.05	38	11.02	108	17.12
4	6.55	74	14.09	39	11.10	109	17.18
5	7.12	75	14.14	40	11.14	110	17.22
6	7.24	76	14.23	41	11.18	111	17.28
7	7.31	77	14.29	42	11.22	112	17.39
8	7.38	78	14.33	43	11.32	113	17.48
9	7.42	79	14.36	44	11.39	114	17.55
10	7.47	80	14.41	45	11.46	115	18.03
11	7.51	81	14.49	46	11.53	116	18.13
12	7.55	82	14.54	47	11.59	117	18.20
13	7.58	83	14.57	48	12.03	118	18.31
14	8.03	84	15.01	49	12.06	119	18.41
15	8.07	85	15.08	50	12.09	120	18.51
16	8.12	86	15.15	51	12.14	121	19.06
17	8.19	87	15.16	52	12.21	122	19.24
18	8.31	88	15.21	53	12.27	123	19.44
19	8.37	89	15.29	54	12.31	124	20.01
20	8.42	90	15.34	55	12.35	125	20.15
21	8.49	91	15.38	56	12.40	126	20.32
22	9.01	92	15.42	57	12.46	127	20.57
23	9.06	93	15.47	58	12.51	128	21.20
24	9.15	94	15.54	59	12.57	129	21.39
25	9.23	95	15.59	60	13.02	130	21.52
26	9.32	96	16.04	61	13.05	131	22.11
27	9.41	97	16.08	62	13.08	132	22.28
28	9.55	98	16.14	63	13.12	133	22.45
29	10.03	99	16.23	64	13.16	134	23.04
30	10.11	100	16.28	65	13.21	135	23.14
31	10.19	101	16.32	66	13.27	136	23.39
32	10.27	102	16.37	67	13.32	137	0.02
33	10.33	103	16.44	68	13.38	138	0.09
34	10.38	104	16.47	69	13.45	139	0.32
35	10.44	105	16.53	70	13.50	140	1.00

COMPARISON MEASURES

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TOTAL NUMBER OF DEPARTURES: 140  
MINIMUM SINGLE ROUTE (ROUND TRIP) REQUIRED FLEET SIZE 24

