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Tmnspn. Rcs: A Vol. 18A. No. 516. pi. 439153. Printed m ths U. S. A. 1984 0191-2607’81 s3.@3+m Pcr&mon Rss L: d. BUS FREQUENCY DETERMINATION PASSENGER COUNT DATA Department USING of Civil Engineering, Transportation Research Institute, Tcchnion-Israel Technology, Haifa, Israel (Received 21 February 1983; in revised form 5 December 1983) Institute of Abstract-The importance of ridership information has led transit properties to increase the amount of manually collected data or alternatively to introduce automated surveillance techniques. Naturally, the bus operators are expected to gain useful information for operations planning by obtaining more accurate passenger counts. This paper describes and analyzes several appropriate data collection approaches for the bus operator in order to set the bus frequencies/headways efficiently. Four different methods are presented to derive the bus frequency: two are based on point check (maximum load) data and two propose the use of ride check (load profile) data. A ride check provides more complete information than a point check, but at a greater cost, and there is a question as to whether the additional information gained justifies the expense. Based on available old profiles, the four methods provide the bus scheduler with adequate guidance in selecting the type of data collection procedure. In addition, the scheduler can evaluate the minimum expected bus runs when the load standard is released and avoid overcrowding (in an average sense) at the same time. Alternative timetables are also investigated in conjunction with minimizing the required bus runs and number of buses for a single route. In this way, the derived headways can be analyzed within an acceptable range while considering the possible changes incurred indirectly to the fleet size. The integration between resource. saving and frequency determination procedures allows the scheduler’s performance to be improved. 1. IN7’RODUCI’ION AND ORJECTIVES It is well known that transit demand varies systematically by season, day-of-the-week, time of day, location and direction of travel. However, the absence of accurate data on travel patterns at the route level has made it impossible to deploy transit resources to match these variations and thus to increase the efficiency of system operation. Accurate ridership information is needed for transit planning and scheduling and also to comply with external reporting requirements (e. g. Section 15 of the U. S. Urban Mass Transportation Act). Consequently, some transit operators have started to use automatic passenger counters while others are adding more checkers to collect the data manually. The primary objective of passenger counts, from the transit operator’s viewpoint, is to set vehicle frequencies/headways efficiently on each route. Other uses of ridership information are in revenue estimation and measurement of dynamic patronage trends. The topic addressed in this paper is two-fold. The first segment involves the setting of bus frequencies in order to maintain adequate service quality and minimize the number of buses required by the schedule. The second is an evaluation tool to efficiently allocate the cost for gathering appropriate passenger load data at the route level. It is common to almost all bus operators worldwide for load profile information along the entire iThis study was written while the author was in 1982 at the Transportation Systems Center (IX), Cambridge, Massachusetts, U. S. A. TSC Support is gratefully acknowledged. 439 length of the bus route (ride check) to be gathered annually or every few years. Usually the most recent passenger load information will be at one or more selected stops along the route where the bus carries its heaviest loads (point check). A ride check provides more complete information than a point check, but is more expensive because either additional checkers are needed to provide the required data or an automated surveillance system is used. There is a question as to whether the additional information gained justifies the expense. The objective of this study is to explore the way in which a bus operator can use the old profile to determine whether the ride check method or the point check method is appropriate in collecting the new data. This paper attempts to achieve this objective through three major parts. First, a brief review is introduced, and thereafter four different methods are presented to derive the bus frequency: two are based on point check (max load) data and two propose the use of ride check (load profile) data. Second, a preliminary criterion is established for determining the appropriateness of each of the data collection methods. Third, in order to complete the evaluation of the point check and ride check methods, altemative timetables are derived along with consideration of the minimum fleet size at the route level. 2. POINT CHECK (MAX LOAD) AND RIDE CHECK (LOAD PROFILE) METHODS 2. 1 Review Generally, bus operators organize ride check surveys routinely at time intervals greater than or equal to one year and update their point check information 40 AVISHAI CEDER where P, is the average (over days) maximum number of passengers (max load) observed on-board in period j, c represents the capacity of a bus (number of seats plus the maximum allowable standees), and yj is the load factor during period j, 0 < ;: < 1. 0. For convenience, let us refer to the product y, c as d,, the desired occupancy on the bus at period j. The standard yi can be set so that 4. is equal to a desired fraction of the capacity (e. g. d, = number of seats). It is worth noting here that if P, is based on a series of measurements, one can take its variability into account. If the stochastic data allow, this can be done, for example, by replacing the average value in eqn (I) with P, + bZj where b is a predetermined constant and Z, is the standard deviation associated with P,. The max load data is usually collected by a trained observer who stands and counts at the bus stop believed to be located at the beginning of the max load section(s). This stop has usually been determined from old ride check data or from information given by a mobile supervisor. Often, these observers are told to count at only one stop during the whole day instead of moving to a different max load point at every period j. In this case the scheduling department identifies the point at which the bus is starting to carry a load associated with the heaviest daily load along the route. This method is referred to as Method I and can be written more explicitly as: $‘=?, j= l, Z I ,..., 9 several times a year for possible schedule revisions (see Vuchic, 1978). It is important to note that the frequency and the cross-sectional characteristics of these data collection procedures should be determined by the sampling techniques used. This statistical aspect, which is not part of this study, can be approached through a variety of literature about sampling and is mentioned specifically in Attanucci Ed al. (198 I). Schedule revisions range from completely new timetables for new or revised routes to daily adjustments that accommodate changes in working hours and school dismissal times. The methods used by the bus operator to set headways are commonly based on existing service standards. These standards are based on two requirements: (i) adequate spaces will be provided to meet passenger demand, and (ii) the upper bound value is placed on the headways to assure a minimum frequency of service. The first requirement is appropriate for heavily traveled route hours (e. g. peak period), and the second for lightly traveled hours. The first requirement is usually met by a widely used peak loud fucfor method (point check), which is similar to the max load procedure-both are explained below. The second requirement is met by the policy headway which usually does not exceed 60 min and in some cases is restricted to under 30 min. Occasionally, a lower bound value is set on the headway by the bus operator, based on productivity or revenue/cost measures. There are also mathematical programming techniques to approach simultaneously the problems of route design and service frequency (see Lampkin and Saalmans, 1967 for an example). Recently such a technique has been adopted to find the appropriate headway so as to maximize the social benefit subject to the constraints on total subsidy, fleet size, and bus occupancy levels (Furth and Wilson, 1981). This model may be shown to be useful in policy analysis. 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 cannot simultaneously determine even spaced headways and uneven spaced headways for situations of scheduling exceptions. 2. 2 MUX loud methodr The purpose of the basic standard used by bus schedulers is to ensure adequate space to accommodate the maximum number of on-board passengers along the entire route, for a given time period (e. g. one hour). Let the time period be denoted asj. Based on the peak load factor, the number of buses required for period j is: where P, is defined as the load in period j associated with the daily max load point. Additional notations are: max i Pii = f P,, and ES j-1 j-l P, = max P, LS where there are q considered time periods; S represents the set of all bus stops i, and P, is a defined statistical measure (simple average or perhaps with the standard deviation consideration) of the total number of passengers which are on-board all the buses departing stop i during period j. Table 1 displays the ride check information which will be used throughout the paper. This is actual data collected on one route in Jerusalem-route 27(A) of Egged (The Israel National Bus Carrier). In Table 1, the first and second columns are the distances (in kilometers) between each two adjacent bus stops and the stop name, respectively. The set of stops S includes 34 i’s excluding the last stop. The first two rows represent the time interval, j = 1, 2,. . . , 14, where each period of one hour is associated with a given column. In the third row are the number of buses scheduled in each period. The fourth row Bus frequency determination using passenger 1. Initial data count A data 441 Table for bus No. 27 direction: 12 59 1. 75 75 20 . 5 75 76 5. 9. 93 99 (25 , 511 102 16. to2 (81) (02 (98 ‘ 08 206 108 19. ,,, 126 (80 (84 192 (92 132 14, (95 195 (55 196 162 19. (93 18. (93 132 159 I. 1 (47 138 (35 (28 I, 7 ,, a t,. (3. ‘(1 I32 10. 9 ,, a 108 96 78 78 78 78 53 33 19 20 (2 \_\_\_\_ \_\_\_\_ 158 20. 208 215 220 252 268 259 28. 280 280 250 28. 295 295 29. 299 252 2. 9 235 236 228 22. 212 2, 6 (80 l-72 (5. 452 ,. O tar (0. 72 40 \_\_\_\_ 180 223 225 239 2. 5 2. 5 2. 5 250 2. 8 2. 3 2. 5 2. 5 2. 5 235 240 2. 0 239 203 198 195 200 (98 190 (78 159 (53 I38 135 115 105 93 95 90 68 \_\_\_\_ 175 235 220 220 220 220 230 255 2. 0 295 3, s 320 320 320 3m 300 290 290 320 250 290 3t0 310 285 255 210 (90 195 (75 (55 (00 (35 90 20 \_\_\_\_ 239 266 255 270 266 263 259 253 29. 265 270 273 253 259 2. 9 239 228 23, 2, 7 (93 $75 ,., 151 1. 7 t. 0 ,, a 95 8. 60 49 . 9 . 9 32 , I \_\_\_\_ 280 351 375 379 375 378 37, 36, 36. 399 37, 37, 35. 37, 357 3. 7 335 239 2. 5 210 196 199 192 165 133 102 77 ;; ii 50 10 i; 42 10 --\_\_ 320 411 395 392 397 3,. 395 398 390 387 390 40, 398 403 403 39. 355 339 3. 7 29. 299 270 25. 256 2. 8 209 192 179 136 120 109 (28 (0, 37 \_\_\_\_ 275 4. 1 450 462 . 95 ., 7 455 465 477 495 . BO 47, 455 474 4,. .,, . 50 . 26 120 350 3. 5 336 339 336 303 25. 2. 9 225 (92 183 (68 ‘ 80 255 26, 25. 273 257 273 285 297 29, 306 32. 3, s 3, 2 315 303 29. 2. 9 2. 0 23. 229 20, ,,. , 53 (38 II iii 51 \_\_\_\_ (05 235 295 308 315 3, 9 325 329 325 3, s 31. 9 320 320 32. 9 325 335 338 3, 9 2. 3 2. 3 239 220 213 200 170 (65 155 153 155 (43 130 129 (15 70 30 . \_\_\_ 90 (08 ,. I 14, 150 I. 7 I. 4 I. 7 f50 (50 1. 4 1. 7 153 159 (59 $55 1. 7 ,,, I,, 4 17 123 (1. Il. iO5 93 57 39 36 30 2, 2. I. 9 6 0 \_\_\_\_ 225 2. 9 2. 5 2. 5 2. 0 23. 23, 228 228 219 219 216 215 20. 198 (85 (7, 1,. 3,. ii9 96 90 8, 69 5, , A ii ii 15 12 , a 9 i 3 -\_\_\_ 37 . 2 42 47 50 5, 5, 52 5, 52 50 50 5. 5. 52 . 9 ., 40. 35 32 28 2, 23 1, 15 12 9 8 4 2 2 2 I , \_\_\_\_ 2. 85 3159 3232 33, 3 3399 3. 20 3. 85 3557 3597 3575 3696 3732 37, 5 3,, 9 359. 3610 350. 3092 3096 2950 2793 25,. 25. 3 2356 2170 , 725 , 673 1596 , 376 12,. (07. (02. 7. 3 356 - - - - represents the policy headway which is equal to 60 min, and the fifth row is the desired occupancy, 4. As can be seen, 4 = 65 has been assigned to peak hours and 4 = 47 (the total number of seats) assigned to off-peak hours. The last column in the table represents ? Pv where each entry in the table is Pu j= l (an average value across several checks). Thus, the daily max load point is the 12th stop with a total of 3732 passengers and P, in eqn (2) refers only to those entries in the 12th row. The second point check method is based on the max load observed in each time period. That is, This method is called Met/&Z. Table 2 lists the value of P., and the values of Pi for allj based on the input data given in Table 1. The comparison between methods 1 and 2 and between the point check and ride check methods using more data sets is performed in a following section. 2. 3 Load profile methodr The data collected by ride check enables the scheduler to observe the load variability among the bus stops. Usually the distribution , of loads will suggest possible improvements in route design. The most common operational strategy resulting from observ- ing the various loads is short turning (shortlining). A turnback point before the end of the route may be chosen, creating a new route overlapped by the existing route. Other route design related actions using the load data are route splitting and route shortening. For the route design considerations, bus operators frequently use the histogram of the average load plotted with respect to each bus stop without relating the loads to the distance between the stops. The only concern of these operators is to identify a sharp increase or decrease in the average load for possible route design changes. This has been observed at SCRTD (Los Angeles), CTA (Chicago)--while using the EZDATA program provided by the company ATE, Egged (Israel), and other bus properties world-wide. A more appropriate way to plot the loads is to establish a passenger load profile. In this technique, the loads are plotted with respect to the distance traveled from the departure stop to the end of the route. It is also possible to replace the distance by the average running time, but in this case it is desirable for the running time to be characterized by low and persistent variations. Two examples of the load profile are given in Figs. 1 and ‘ 2, exhibiting the data of two time periods appearing in Table 1. Each asterisk in the figures represents five passengers. The area under the load profile curve is simply passenger-miles, or in this example, passenger-kilometers, both of which are AVISHAI CEDER Table 2. Output indication of variables used in methods 1 and 2 320 1259 1359 1459 , 559 284 389 ., 1 0 0. 0 0. 6 ‘.......\*‘... 50 100 150 2po ..\*.\*\*..\*\*.....\* ................ ................ ................. ................... .................... 2. 1 2. 9 3. 2 3. 5 3. 9 4. t 4. 7 5. 3 5. 5 5. 9 9. 5 5. 7 7. 3 7. 7 9. I 8. 5 9. 1 9. 5 10. 0 10. 4 IO. 6 10. 9 ,,. I 11.. 11. 5 12. 1 ‘ 2. 5 13. 2 13. 9 I.. 1 14. 8 15. 0 ..................... ..................... ..................... ....................... ...................... ........................ .......................... ........................... ........................... ............................. ................................ ................................. ..................................... ..................................... ................................ .............................. ’ ........................... ........................ ....................... ....................... ...................... ...................... .................... ................ ............. ....... ... Fig. 1. A load profile for one morning time period (8: 00-8: 59) based on the data in Table 1. Bus frequency determination using passenger count data 443 NIJMSER PISSENGERS OF FOR INTERVAL ~500 TO 1559 DlSTlNcE (KY. 1 50 - NUMBEP PAssENGERI OF 200 250 300 ’ 350 400 450 500 I 100 150 L........ 1......... 1........ L......... L...\*.....~..\*.. \*...~...\*\*.........\*..\*..~.....~.............\*..\*...\*.....................\*.............. ........................................................................................... ............................................................................................. .................................................................................................... ................................................................................................ .............................................................................................. .............................................................................................. ................................................................................................ .................................................................................................... ................................................................................................. ............................................................................................... .............................................................................................. ............................................................................................... ............................................................................................... ............................................................................................... ........................................................................................... ...................................................................................... ..................................................................................... ......................................................................... ...................................................................... .................................................................... .................................................................... .................................................................... ............................................................. ..................................................... .................................................. .............................................. ....................................... ..................................... .................................. ............................ ...................... ........... Fig. 2. A load profile for one afternoon time period (15: 0@-15: 59) based on the data in Table 1. measures of productivity. If a straight line is drawn across the load profile at the point where the number of passengers is equal to the observed average hourly max load, then the area below this line but above the load profile is a measure of the non-productive service. When method 2 is used to derive the headways, and dj is equal to the number of seats then this measure is the empty seat-miles (or empty seatkilometers). Figure 1 is characterized by a relatively large value of empty seat-kilometers per bus in comparison to Fig. 2. However, the additional information supplied by the load profile enables one to overcome such an undesirable characteristic. This can be done by introducing frequency determination methods which are based on passenger-miles rather than on a max load measure. The first load profile method considers a lower bound level on the frequency or an upper bound on the headway, given that the bus capacity constraint is held. Method 3 is: q? = max One way to look at method 3 is that the ratio A,/L of the load P, (regardless of its statistical definition) as opposed to the max load (P,) in method 2. Method 3 guarantees, on the average basis of P,, that the on-board passengers at the max load section will not experience crowding above the given bus capacity c. This method is appropriate for frequent cases in which the schedulers wish to know the number of bus runs they can expect to reduce by relaxing the desired occupancy standard, avoiding overcrowding at the same time. This allows them to handle the following: (i) demand changes without increasing the available number of buses; (ii) situations in which some buses are needed elsewhere (e. g. breakdown and maintenance problems, or emergencies); (iii) fewer drivers than usual (e. g. due to budget cut, or problems with the drivers’ union). On the other hand, method 3 can result in unpleasant travel for an extended distance in which the occupancy is above 4. To eliminate or to control this possible undesirable phenomenon, another method is introduced. Method 4 establishes a level of service consideration by restricting the total route distance having loads greater than the desired occupancy. Method 4 takes the explicit form: is an average representative A. P. -A-, 1 dj. L c 1 [ [ 4. L’ Ai1 pj c where Ii is the distance between stop i and the next stop (i + l), Aj is the area in passenger-miles (km) under the load profile during time period j, and L is the route length. The other notations are previ )usly defined in eqns (l)-(3). 4?= max St. 1 Ii I jJj. L, \*I) 444 AVISHAICEDER by time of day are same to that indicated in Table 2, and for all five sets the capacity is c = 80 passengers. In method 4 based on eqn (5), three values are assigned to /I, for all j’s: 0. 1, 0. 2 and 0. 3. That is, 10, 20 or 30% of the route length is allowed to have an observed occupancy, P, exceeding the desired one, 4. The results for route 27(A) appear in Table 3. The headway results of the four methods are compared graphically in Fig. 3 where the results of method 4 are for only the 20% limit case (8, = 0. 2). Similarly to Fig. 3, the results of the remaining four data sets are displayed only in the computer generated graphical form in Figs. 4-7. . These illustrations are used for further analysis of the results. The first comparison can be made between method 1 and method 2 for the point check decision. Obviously, it is less costly and more convenient to retain an observer at one bus stop during the entire working day, than to assign the same observer or others to a different stop at every period j. This candidate bus stop is the one characteiized by P, (see eqn (2)). The comparison between the two methods is performed by the ,$ test between two sets of actual observations-P., vs P, for each data set (see Ceder and Dressier, 1980). The results are as follows: where I, = {i: (P,,/F,) > d,} or 4 is the set of all stops i in time period j such that the load Pq exceeds the quantity of 4 times the number of buses determined iteratively by F,, and pj is the allowable portion of the route length at period j in which Pti can exceed the product (4)()(d,). The other notations in eqn (5) are previously defined. By controlling the parameter /Ii it is possible to establish a level of service criterion. Note that for /I, = 0, /I, = 1. 0 method 4 converges to method 2 and method 3, respectively. 2. 4 Results of actual data and comparison A pL/l program has been written for all the four methods. This program, in addition to calculating the bus frequencies, determines the associated integer headway (in minutes) by simply dividing the length (in minutes) of a considered time period j by 4., and rounding it to the nearest integer. The headway information is essential for the timetable preparation, as is explained in the next section. The input data presented in Table I and also the data taken from four more routes have been run by the program. The additional data are four Egged routes: 2(A), 2(B), 12(A), and 39(A)---all from Jerusalem. Their policy headway and desired occupancy Route (Direction) 27(A) 2(A) 2(B) d. f. 13 16 18 14 16 X2 63. 24 14. 59 58. 51 492. 82 117. 82 null hypothesis about equal methods (at the 5% significance level) reject don’t reject reject reject reject I&4) 39(A) Bus frequency determination using passenger count data 445 BUS NO. 27 , DIRECTION A LEGEND o - METHOD + - METHOD . - METHOD 1 2 3 L (BY2OP a - METHOD 0’. 7: oO . . 9 . . oo 11-00 . . TIME 13. 00 OF DAY ’ \* 15. 00 ’ . 1x00 1 . 19: oo 21 00 g Fig. 3. Comparison of headway results for route 27(A). Consequently, only in route 2(A) can the daily max load point replace the hourly max load point. The PL/l program provides this comparison. The graphical comparison between the headways in Figs. 3-7 shows the expected result: method 2 always gives the minimum headways while method 3 results in the highest headways (except in 2 out of 82 time periods). Another characteristic of the headways, exhibited particularly in Figs. 4 and 5, is that the given policy headway (60min) is used during off-peak hours. A point worth mentioning is that the results might be sensitive to the length of the time intervalj and that different time intervals may be used for peak and off-peak hours. Further analysis and comparison of the results are addressed in the following two sections. 3. A PRELIMINARY CRITERION IN DETERMINING FURTHER DATA COLLECTION METHODS In this section an assumption is tested that particular load profile characteristics suggest the data collection method to be used. The basic idea is to BUS NO. 2 , DIRECTION “ A" . - METHOD 3 6, 04.. . . . . . . I a. . -METHOD LCBY20%1 \* ’ . ’ 6. 00 800 10 00 12. 00 TIME OF 14. 00 DAY 16: OO 16 00 20. 00 22: oo Fig. 4. Comparison of headway results for route 2(A). 446 AVISHAICEDER BUS NO. 2 , DIRECTION ‘ B’ . 6 \_ METHOD L CBY20T. l 01 . 5: oo . . 7 00 . 9 00 \* 1100 . TIME . 13. 00 \_ 15 00 OF DAY .., 17 00 . 19 00 . . 21 00 23 00 Fig. 5. Comparison of headway results for route 2(B). provide the bus operator with adequate preliminary guidance in selecting the type of method based on old load profiles. The assumption to be investigated is that a relatively flat profile suggests the use of a point check procedure (method 1 or 2) whereas a ride check procedure (method 3 or 4) would be appropriate otherwise. One property of the load profile is its density, p. This is the observed measure of total passenger-miles (total ridership over the route) divided by the product of the length of the route and its maximum load (passenger-miles which would be observed if the max load existed across all the stops). Thus, the load profile density for hour j, pj, is P’= e. The load profile density is used to examine the profile characteristics. High values of p indicate a relatively flat profile, whereas low values of p indicate a significant load variability among the bus stops. A BUS 60 NO. 39 , DIRECTION “ A" LEGEND 4% $ s 2 L2. 36. METHOD ‘ (BY ZCr%l = 30. p' I 9 i P 12. 6. 24. 18. 0. 1 6 00 . a 00 . 10 00 . 12. 00 TIME OF woo DAY 16 00 18. 00 20 00 2200 Fig. 6. Comparison of headway results for route 12(A). Bus frequency determination using passenger count data 447 BUS NO. 12 , DIRECTION ‘ A" LEGEND o \_ METHOD + . METHOD METHOD 1 ;/ 2 3 : ,’ / ;\* I 8 ’ METHOD L (ByZoZl 0’ 500 I - I 1 7 . oo 9: oo 11: oo I . TpF ; nY15: 00 '. 17: oo ' 19: oo ' ' Fig. 7. Comparison of headway results for route 39(A). 3. 1 Mathematical analysis One way to approximate the observed shapes of profile curves is by using a mathematical model. The lognormal model has been selected for this purpose since it provides a family of curves which can be controlled by varying the parameters p and u. The lognormal model takes the form: f(x) =.& The equation satisfying (df(x)/dx) = 0, is e-oDX-\*~/262; x > 0. the optimum (7) conditions, x,= d-“= (8) This continuous model can only approximate some of the observed load profiles since it has only one peak and represents monotonically increasing and decreasing functions before and after this peak, respectively. Nonetheless, this model is useful in observing some general differences between the ride check and point check methods. In order to be able to compare the methods, f(x) is used as a normalized load (the load divided by the max load) and x is used as a normalized distance (the distance from the departure stop divided by the length of the route). At a given time interval of one hour, j, the considered max load is Pi = 650 passengers. Given that dj = 65 and that c = 100, the determined frequency and headway for both methods 1 and 2 are 4 = 10 and Hj = 6. By applying this information to methods 3 and 4, using a variety of lognormal curves, one obtains the frequencies and headways shown in Table 4. The results in this table are aranged in increasing order of density. For method 3, the capacity constraint determines the values of F and H up to an including p = 0. 64 and up to different p values (if any) for method 4. Examples of the lognormal normalized curves are shown in the computer generated Figs. 8 and 9 for two p and variety of p values. Note that the relative location of the max load point can be found by eqn (8). From Table 4 it appears that for method 3 the ride check (load profile) data results in the same rounded headway as for the point check (max load) data for p 2 a where 0. 84 < a 5 0. 87. For method 4 the ride check and point check information tend to yield the same headways for p 2 ai where i = 1, 2, 3, for the 10, 20 and 30% cases, respectively, and 0. 34 < a, I 0. 43, 0. 50 < a2 I 0. 56, and 0. 64 < a, 50. 68. 3. 2 Observed densities and discussion The five data sets mentioned in the previous section were also subject to the load profile density examination. The pi values for each considered hour j, based on eqn (6), were calculated and are shown in Table 5. For example, in Fig. 10, which is part of the PL/l program output, one can visually compare the load profiles associated with the highest and the lowest p value of data collected on route 39(A). As can be seen from Table 5, none of the p values exceed 0. 8. This suggests that one cannot reach, by calculation, same headways for method 3 and method 2. Figures 3-7 reveal that the determined headways of method 3 are always greater than those of method 2 excluding the cases of policy headway. However, no clear cut conclusion can be drawn when trying to associate the p values in Table 5 with those 448 Table 4. Frequencies (F) and headways log-normal AVISHAI CEDER (H) for different load profile configurations (derived from the model) using methods 3 and 4’ Method 3 profi 1e density T by 10% H F 7. 60 H Method 4 20% H 9 9 9 9 9 8 7 : 8 -%6 6 6 6 6 6 6 6 6 6 1 by by P F F F 30% H 9 9 9 9 9 9 0. 18 0. 25 0. 27 0. 32 0. 34 0. 43 E 0: 48 0. 50 0. 56 0. 57 0. 59 0. 62 0. 64 0. 68 0. 75 0. 76 0. 78 0. 84 0. 87 \*For Note: 6. 50 6. 50 6. 50 6: 50 6. 50 6. 50 6. 50 6. 50 6. 50 6. 50 6. 50 6. 50 6. 50 6. 77 7. 46 7. 63 7. 77 8. 41 8. 72 9 9 9 9 E% 9’ z 9 9 9 9 9 9 9 : 7 7 -4. 8. 46 6. 50 8. 36 7. 55 9. 00 7 9 7 7 -i5: 6 6 6 6 6 6 6 6 6 6 6 6 6 6. 50 6. 50 6. 50 6. 50 6. 50 7. 05 8: 05 E 7. 35 x 9: 31 8. 85 9. 04 9. 42 9. 36 9. 68 9. 87 9. 76 9. 92 6. 50 6. 50 6. 50 6. 50 6. 50 6. 50 z! 9: 45 9. 05 9. 92 9. 76 9. 81 9. 65 9. 79 9. 87 9. 86 9. 93 9. 97 9. 96 9. 97 constraint ? E 8’ 6: 50 9 6. 50 9 9. 27 6 8. 16 7 8. 46 7 7. 80 7 8. 19 7 8. 72 -b 8. 76 6 9. 23 6 9. 72 6 9. 46 6 9. 82 6 Methods 1 and 2: Uhenever F-10. H= 6 where d F= 6. 50, H= 9 the capacity = 65, c-100. is met. in Table 4 regarding the comparison between methods 4 and 2. Figures 3-7 clarify this by illustrating the results of method 4 for the 20% case. The matchings (same headways for methods 2 and 4) across all the five data sets range between p = 0. 538 (route 2(B), for the hour 22: 00-22: 59) and p = 0. 744 (route 39(A), for the hour 16: 00-l6: 59). On the other hand, the non-matching cases range between p = 0. 457 (route 2(B), for the hour 8: 00-8: 59) and p = 0. 777 (route 12(A), for the hour 15: 00-15: 59). Consequently, when applying method 4 to the observed load profiles, the results of the lognormal model cannot be explicitly used and an actual comparison between methods 2 and 4 should be performed. In practice, the bus operator wishes to save bus runs and eventually to be able to perform the matching between demand and supply with fewer buses. As is shown in the next section, different headway values do not necessarily save bus runs or reduce the required fleet size. However, the analysis made about the profile density measure can be used by the bus operator as a preliminary check before entering a more comprehensive analysis. The following are practical observations: (i) for densities below 0. 5, p-o 66 OK 0 1 . 2 . 3 Fig. 8. Four approximated load profiles based on the log-normal model (a = 1. 00). Bus frequency determination using passenger count data Fig. 9. Four approximated load profiles based on the log-normal model (u = 1. 50). savings are likely to result by gathering the load profile information and using either method 3 or 4 (alternatively for such low p values, the profile can be examined for short turn strategies); (ii) for densities between 0. 5 and 0. 85, it is recommended that an actual comparison be made between the point check and ride check methods-along with further saving considerations (see next section); and (iii) for densities above 0. 85 it is likely that the majority of the required information for the headway calculation can be obtained from a point check procedure (either method 1 or 2). 4. ALTERNATIVE The TIMETABLES AND FLEET SIZE possible to initiate the task of scheduling buses and crews to the previously determined trips. Naturally, the bus operator wishes to utilize his resources more efficiently by minimizing the number of required buses and the cost of the crew. To accomplish this, the scheduler examines different timetables during the bus and crew assignment processes. This is done by shifting the departure times or by reducing the number of departures without referring usually to the initial source of passenger loads-the profile. Therefore, it is desirable to extend the analysis deriving appropriate headways, to an evaluation of timetables in conjunction with the required resources. 4. 1 Construction of timetables The number of bus runs determined by the timetable and eventually the number of buses required, is sensitive to the procedure used by the scheduler to CONSIDERATION AT THE ROUTE LEVEL products of the derived headways are the timetables for the public, the bus drivers and supervisors. Once the timetables are constructed, it is Table 5. Load profile densities @) for five data sets I 500. ! 6: 00 7: oo 8: 00 9: oo lo: oo Time Interval : - 6: 59 - 7: 59 - 8: 59 - 9: 59 - 10: 59 - 559 : Route Z(A) v-e 0. 489 Route Z(B) Route 12(A) ll: oo 12: oo 13: oo 14: oo 15: oo 16: 00 17: oo l&O0 19: oo 20: oo 21: oo 22: oo 23: 00 - 11: 59 12: 59 13: 59 14: 59 15: 59 16: 59 17: 59 18: 59 19: 59 20: 59 21: 59 22: 59 23: 59 0. 668 0. 557 0. 687 0. 548 0. 687 0. 477 0. 694 0. 652 0. 699 0. 606 0. 632 0. 73j 0. 610 0. 524 0. 588 0. 543 \_\_\_ 0. 524 0; 702 0. 752 0. 457 0. 586 0. 592 0. 647 0. 620 0. 679 0. 764 0. 662 0. 717 0. 722 0. 618 0. 673 0. 633 0. 588 0. 538 0. 546 0. 661 0. 705 0. 625 0. 731 0. 637 0. 589 0. 680 0. 739 0. 740 0. 712 0. 777 0. 640 0. 565 0. 650 0. 509 --a \_-\_ -se -me \_\_\_ --0. 563 0. 567 0. 715 0. 765 0. 717 0. 672 0. 636 0. 733 0. 723 0. 641 0. 712 0. 639 0. 576 0. 593 \_\_\_ \_\_\_\_\_ Route 27(A) \_-\_ 0. 651 0. 561 0. 589 0. 674 0. 594 0. 559 0. 619 0. 644 0. 599 0. 691 0. 744 0. 626 0. 657 0. 544 0. 686 0. 610 0. 577 \_-\_ Route 39(A) 0. 0 0. 3 0. 4 0. 7 1. 1 1. 3 1. 7 2. 3 ?. I 2. 7 3. 1 3. 5 3. 9 4. 4 4. 9 ................................ .................................... ................................... .................................... ....................................... ......................................... ......................................... ......................................... ......................................... .................. ................... ................... ................... ................... ................... ................................... 5. 6 5. 1 ‘ 6. 2 6. 4 6. 7 7. 1 7. 5 7. 8 8. 2 8. 4 8. 6 9. 0 9. 1 9. 2 9. 5 9. 6 ......................................................................... ......................................................................... ...................................... ...................................... ...................................... .; ................................. .............................. ......................... .................... .............. .............. ... ... .\* .. \*\* ............................. ............................. ........................ ........................ .................. .................. ................ ............. ............. Fig. 10. Two load profiles of route 39(A) with the highest density @ = 0. 744) on the left and the lowest density @ = 0. 544) on the right. construct the departure times. Some bus operators routinely round the frequency 5 to the next highest integer and then calculate the appropriate headways for the considered time period. By doing so, they increase the number of daily departures beyond what is needed to appropriately match the demand with the supply. Such a procedure may result in nonproductive runs (many empty seat-miles). For example, in Table 3 the number of daily required departures, F 4, is 77. 01, 55. 64 and 73. 24 for methods j= l 2, 3 and 4 (20% case), respectively. When the quantity F, is “ rounded up, " one obtains respectively: 85, 65 and 80 daily departures for these three methods. Obviously, by rounding k; to the next highest integer, the scheduler increases the level of passenger comfort but, at the same time, causes an unnecessary operating cost. However, in some cases the “ round up" procedure may be justified if the scheduler uses the Pq quantity as an average load whereas the variance of the load is high. In this case (provided that additional runs are made by rounding up Fj), the possible overcrowding situations may be reduced as opposed to increasing the average empty seat-miles. Nonetheless, to overcome the problem of highly variable loads, one can use a statistical load measure which considers its variance as an input to a frequency method (see remarks in eqn (1)). Another characteristic of the existing timetables is the repetition of departure times, usually every hour (see Vuchic, 1978). These easy-to-memorize departure times are based on the “ clock headways": 6, 7. 5, 10, 12, 15, 20, 30, 40, 45 and 60 min. Generally, headways less or equal to 5 minutes are not considered by schedulers to influence the timing of passenger arrivals to a bus stop. The clock headway is obtained by rounding the derived headway down to the nearest of the above “ clock" values. Consequently, and similar to the “ round up" frequencies, the clock headways require a higher number of departures than what is actually necessary to meet the demand. In order to keep the total daily number of departures as close as possible to the sum of the obtained Fj’s by the four methods, the derived headways in Table 3 and Figs. 3-7 are simply based on the “ round to the nearest integer" procedure. Note that for a high frequency value it may turn out that rounding Fj result in fewer departures than rounding the derived headway. However, for high frequencies, the timetable is not required. Also, if 5 is rounded first it is necessary to perform a second rounding on its associated headway (since timetables are built by headways-not frequencies). This by itself may ultimately decrease the accuracy of matching the demand with the number of departures. An attempt is made in Table 6 to construct six daily timetables for methods 2, 4 and 3 using both the derived and the clock headways based on the information in Table 3. The only incompatability is that Bus frequency determination using passenger count data 451 Table 6. Various timetables for bus 27(A) based on methods used and considered headways Y : I9 ii: 01 : 3a : oa : 57 : 15 a: 17 : 22 : 3a : 29 : 59 : 36 9: 14 : 43 ~24 : 50 : 34 : 57 : 44 14: 04 : 54 : I1 10: 04 : 1s : 15 : 25 : 26 : 32 : 37 : 39 : 4a ~46 : 59 : 53 11: 09 15: OO : ia : 08 ~27 : I6 ~24 : 36 : 45 : 32 : 54 : 40 12: 03 : 4a : 13 : 56 : 23 16: 06 : 33 : la : 43 : 30 : si : i5 17: 04 : 30 : 12 : 45 : 20 a: 00 : 2a : 20 : 36 : 40 : 44 9: oo : 52 : lO ia: m : 20 : la : 30 : 36 : 40 : 54 : 50 19: oa 1o: oo : 19 : lO : 30 : 20 : 41 : 30 : 52 : 4o 20: 24 : 50 21: 17 11: OO : 07. 5 : I5 : 22. 5 : 30 : 37. 5 : 45 : 52. 5 12: oa : lO : 30 : 40 : 50 13: oo : 06 : 12 : la ~24 : 30 : 36 : 42 : 4a : 54 14: oo : 06 : 12 : la ~24 : 30 : 36 ~42 : 4a : 54 1s: oo : 07. 5 : 15 z22. 5 : 30 : I5 : 52. 5 16: Ml : 12 ~24 : 36 : 4a 17: oo : 07. 5 : 15 : 22. 5 : 30 : 37. 5 : 45 : 52. 5 la: 00 : 15 : 20 : ll : 40 : 19 a: 03 : 27 : 29 : 35 : 55 : 43 9: 13 : 5i : 23 : 59 : 33 14: 06 : 43 : 13 : 53 : 20 10: 03 ~27 : 14 : 34 : 25 : 41 : 36 : 4a : 47 : 55 : 5a 15: oz ii: 08 : lO : 17 ii; : 26 : 34 : 3s : 44 ~42 I : 53 : 5Ll ! lZ: Oi : G : 12 16: oa : 21 : 34 : 34 : 44 : 47 : 12: 54 17: W : la ~27 : 36 : 45 : 54 ia: oa ~27 ~46 : 59 19: ll : 23 : 35 : 47 2o: zo 21: 15 ! uer~ved LIOC): Headway 00 12~30 16 00 7 : 12 : 23 ~24 : 46 : 36 a: lo : 4a : 36 17: w : 55 : 07. 5 9: oa I: 00 : 22. s : I5 : 21 : 10 : 30 : 34 : 20 : 37. 5 : 22. 5 : 46 : 30 : 30 : 45 : 37. 5 1o: oo : 40 : 52. 5 : 15 : 45 : 50 14: oa : 30 : 52. 5 I: 00 : 06 : 45 : 10 : 12 la: 00 1l: OO : 15 : 20 : 18 : I2 : 30 : 30 ~24 : 45 : 24 : 40 : 30 : 36 19: oo : 50 : 36 : 4a 1: oo ~42 : 12 ~24 12: oa : 07. 5 ~48 : 15 : lS : 54 : 36 : 30 : 40 : 22. 5 15: oo : 45 : 30 : 07. 5 2o: oo 13: oo : 45 ~27. 5 : 15 : ll : 45 : 22. 5 21: 30 : 52. 5 : 30 2: oo z37. 5 : 10 : 45 : 44 : 20 : 52. 5 20’) i : . I : oo ’ I : lO : 2o : Jo : 40 : 50 2o: oo : 45 21: 30 ! : z24 i ( i:: ; i ~55 uETmb3 He4dw4y , Clock HeadMy 14: os 7: oo 13: so 19: 5 : 20 14: oo : 4 : 14 : 40 : 07. 5 2o: a : 23 : I5 a: 00 21: c : 32 : 20 : 22. 5 : 41 : 40 : 30 : 50 9: oo : 37. 5 : 59 : 12 : 45 15: 08 : I4 : 52. 5 : ia 15: oo ~36 : 2a : 4a : 10 : 3fl 1o: w : 20 : 4a : 15 : 30 : 5a : 30 : 40 16: lO : 45 : 50 : 25 11: OO 16: OO : 40 : 12 : 15 : 55 ~24 : 30 11: 08 : 36 : 45 : 20 : 48 17: oo : 32 . 44 12: oo : 12 I56 : 15 : I2 : 30 : 36 la: 16 : 44 : 45 : 48 19: 07 13: oo 18: OO : 26 : lO : 20 : 20 : 40 : 45 : 30 20: 23 19: oo 21~23 : 40 : 15 I 1 the clock headway technique includes a value of 7. 5 minutes whereas the derived headways do not allow non-integers. The transition between the hourly periods for the derived headway is based on a smoothing rule that use the rounded down average headway whenever a transition from one hour to another occurs. For example, in method 2 the transition between the departures 8: 59 and 9: 14 is based on rounding down the average headway of 21 and 1Omin. A point worth mentioning here is that the schedulers often have the knowledge of different load patterns during one period j, e. g. more loads in the first half hour than in the second. In this case they can request splitting or changing the time period j for further data collection. Also, they can insert more departures in the heavy-load interval than in the remaining interval, while ensuring the approximate total of Fj departures. Further consideration about creating timetables appears in a report by Ceder (1983). This includes development of methods to construct timetables with even headways and timetables with even (average) loads on individual buses while the headways are unevenly spaced. 4. 2 Single-route fleet size examination Within a large-scale bus system, buses are often shifted from one route to another (interlining) and they frequently perform deadheading trips in order to operate a given timetable with the minimum required buses. It is desirable to analyze the procedures to construct timetables and scheduling buses to trips simultaneously. However, due to the complexity of this analysis, these two procedures are treated separately. Therefore, in a bus system with interlining routes, the alternative timetables can be evaluated on the basis of the total number of required departures. This can serve as an indicator for the number of buses required, but without inserting each alternative timetable to the scheduling procedure, it will be difficult to predict the effect on the fleet size. One fleet size test that can be performed is based on the assumption that interlinings and deadheading trips are not allowed and that each route operates separately. In this case, given the mean round trip time, the minimum fleet size for that route can be found similar to the formula derived by Salzbom (1972). Let T be the round trip time including the layover and turn around time and that departures occur at discrete time points: t,, t2, r,, . . . , t,. Also, let N, be the number of departures between and including the two departure points t, and t, such that three conditions (i) are fulfilled: t, > tr, (ii) t, - tr I T and (iii) t,+, - t, > T. Given that if t, = t, then the first tk, k = 1, 2,. . . , n to agree with the first two conditions is t,. the minimum single-route fleet size, N,,,, is: Nmi,= max k i k= l Nk Following Salzborn arguments, eqn (9) simply means that N,, is the largest number of buses departing in any time interval of length T. This result can