fied version of the technique. Further, the analysis shows that some of the less visible but recurring cost components (deadheading and relief costs) may significantly affect the total annual costs of a proposed garaging system. On the other hand, new construction costs, which may seem highly important during the earlier planning stage, may have marginal ramifications for total system costs when spread over the life of the project.

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The views expressed in this paper are ours and do not necessarily reflect those of UMTA or any other agency named or referenced in the paper.

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Abridgment

Practical Methodology for Determining Dynamic Changes in Bus Travel Time

AVISHAI CEDER

Research undertaken to develop and examine two methods of treating bus travel time—(a) measurement and (b) processing and analysis for planning needs—is reported. These methods are intended mainly for the scheduler responsible for scheduling buses to trips so as to take into account any dynamic changes in bus travel time. The motivation for the research comes from the existing system at Egged (the Israel National Bus Carrier), which uses a single mean value for bus travel time (for a given bus line) for all days of the year. The method chosen for data collection on bus travel time is based on the use of the tachograph, which is currently an integral part of bus equipment. The tachograph allows for a current report on departure and arrival times of trips through the turn of a special knob by the driver. In comparison with other information systems being tested today, the tachograph is simple and inexpensive to use. The accumulated data on bus travel time are transferred by use of a statistical method to calculate means and standard deviations for three cross sections: daily, weekly, and seasonal. The criteria for the statistical method are that it be simple, flexible, systematic, and practical so that the outcome will be compatible with the objective of planning work schedules for buses.

Egged (the Israel National Bus Carrier) operates a widespread geographic network of about 4000 lines. These lines are urban, suburban, regional, and intercity, with a vehicle fleet size of more than 5000 buses covering an average of 54 000 daily trips. The planning process for such a vast number of daily trips is clearly a complex and challenging undertaking.

One of the more crucial input elements in the planning process is bus travel time (BTT). This element depends on trip time (hour, day, week, season), number of passengers, and the habits of each individual driver. This paper describes a method implemented for Egged on how to measure and consider BTT, particularly from a practical viewpoint. Before demonstrating this method, however, let us represent the general planning process of a large-scale bus company and indicate how travel time affects this process.

The planning process is composed of five major components: (a) planning bus stops, (b) planning bus routes, (c) setting timetables, (d) scheduling buses to trips, and (e) assigning drivers. Since interrelations exist among the five components, it is desirable to analyze them simultaneously. If so, BTT would influence the whole planning process. However, the complexity of the system induces separate treatment for each component, a process in which the outcome of the treatment of one component is fed as an input into the next component. Consequently, the component that is directly affected by the dynamic changes in BTT is the procedure of scheduling buses to trips.

Recently, Egged has experimented with a fully optimal bus-scheduling algorithm (1) in an attempt to replace currently used manual planning procedures (60 schedulers using Gantt charts). However, because of the limitations of this algorithm, an approximate procedure incorporating a man-computer interface was requested. This man-machine interactive scheduling procedure has been developed but has not yet been fully implemented (2). This method allows for the inclusion of practical considerations that experienced schedulers may wish to introduce in the schedule.

IMPORTANCE OF BTT

Extensive investigation of BTT has been carried out for two main purposes: (a) to find applied methods and directions for reducing the mean travel time and (b) to simulate bus operations in order to achieve appropriate control strategies for the improvement of level of service.

The first purpose represents a clear advantage for both bus passengers (saving travel time) and the operator. The operator can either reduce fleet size, increase the frequency of service, or release more recovery time for drivers at the arrival end point. This purpose was also included in the framework used by the Transport Operations Research Group at the University of Newcastle-upon-Tyne, which conducted research on the operation of bus routes (3-5). The reduction of the mean value of BTT could be attributed to those actions that attempt to minimize the variation of sources of irregularity, including (a) different numbers of boarding passengers, (b) different passenger boarding times, (c) different travel times between bus stops, (d) the probability of buses stopping at stops, and (e) undisciplined departures from terminals.

The second purpose for using BTT is related to simulation studies. The simulation program usually serves as a tool for (a) evaluating planning control strategies (6,7) for such changes as bus stops, routes, and timetables and (b) evaluating operational control strategies for both off- and on-line systems (8,9) in order to avoid such conditions as bunching of buses, running behind schedule, and carrying an undesirable number of passengers. For example, one simulation study (9) found, as expected, that variability in BTT has an important effect on the reliability of bus service and can be reduced through priority operation and, in particular, through on-line control.

Nevertheless, these investigations were not planned to specifically address the component of scheduling buses to trips. The purpose of this paper is to present a simple method of both measuring and determining BTT so that the scheduler can use it in either a manual or an automatic (fully computerized) mode. At present, Egged schedulers obtain the mean value of BTT and refer to it on Gantt charts. The prime objective of the skilled scheduler is to minimize the required fleet size for a given fixed schedule. Unfortunately, because of the large number of daily trips made by Egged (54 000), the mean BTT is updated once a year, after a two-day period of observation. This mean BTT is used for all hours of a day, all days in a week, and all weeks in a year.

MEASUREMENT OF BTT WITH AN ELECTRONIC TACHOGRAPH

As previously stated, Egged operates about 4000 bus lines, each of which has a single mean value of BTT. Since BTT is a stochastic variable, it would be desirable, for planning purposes, to know the mean values mainly as a function for three types of cross sections: daily, weekly, and seasonal. Naturally, to obtain such information, a wide-ranging sample that covers all 4000 lines would be needed. To do this manually would require great resources, the costs of which would not be justified by the results to be obtained.

The tachograph is a well-known instrument developed nearly 50 years ago, mainly as a follow-up on driver behavior and to collect aggregate data on distance, time, and speed. The instrument is connected to the speedometer as data are delineated on a diagram chart. The chart turns at a standard pace, and three styluses register vehicle speed, the time the vehicle is stationary or in movement, and travel distance. There is the option of collecting additional data with a fourth stylus. The chart generally serves for a 24-h time period (for safety needs, it is possible for the chart to complete a turn in 20 min and then erase itself). There are also tachographs that allow for the use of seven charts for the week, which can be removed after that time.

Today, the tachograph is standard equipment on new buses. Of course, the advantages of the tachograph over other data-collecting instruments are that it is inexpensive and readily applicable to buses.

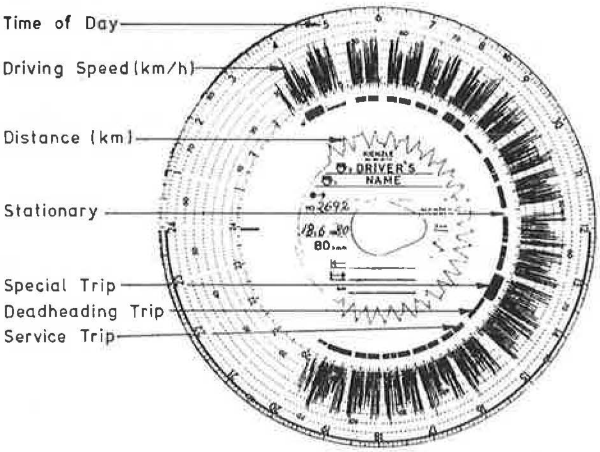
In a project carried out by Egged (10), a system for coordinating the characteristics of the tachograph in order to measure BTT was recommended. To do this, an additional capability must be added to the tachograph so that the driver can indicate the start and end of trips. The recommendations of the Egged project were applied, and Egged's latest order for 1150 Mercedes buses (which were to enter service during 1980) included the tachographs, which will also serve to measure BTT.

Of the 54 000 daily trips made by Egged buses, 36 000 are service trips, 14 000 are deadheading trips, and 4000 are special routine trips. In order to identify these trips, it was recommended that a special knob be installed on the tachograph that can be adjusted to the three different trip types. The direction of this knob should be made conspicuous to the driver (by eye-catching lettering or various colored lights), in order to ensure compatibility between the type of trip and the correct position of the knob.

An electronic tachograph designed for daily diagram charts of 24-h periods was chosen. Figure 1 shows an example of a tachograph diagram chart for 20 trips during a period from 3:30 a.m. to 8:00 p.m. Under the speed diagram (in the example, the speed range is up to 80 km/h, which is suited to urban buses, whereas for interurban buses the speed range is up to 125 km/h), there are indications for type of trip along the time horizon. The first trip is a short one, from the bus depot to the origin station (deadheading trip). The next is a special trip that returns as a deadheading trip. Then the service trips begin and among these are two special and two additional deadheading trips. Finally, there is a deadheading trip when the bus returns to the depot. The differences between the types of trips are indicated by bands of varying widths recorded along the time horizon on the diagram chart.

The processing of travel-time data can be carried out manually by coordinating it with the driver's work schedule (which trip was carried out at all times in relation to the plan). On the other hand, manual processing is suited for sample and ad hoc needs (a skilled worker can analyze a diagram chart

Figure 1. Diagram chart covering 20 trips from 3:30 a.m. to 8:00 p.m.



in less than 5 min). When the bus fleet supplies data in the range of 1000 or more diagram charts daily, an alternative is to process the data by using a computer. Data are inputted by means of an optical reader. The Kienzle Company has developed a computerized system (Kienzle FOS 1613) that can analyze data recorded on the diagram charts in seconds by means of an optical electronic process. Standard and supplementary data can be fed into the unit either manually, by means of a floppy disc unit, or by data communications.

The Kienzle computer program is not suited for analyzing and processing travel-time data and is intended for aggregate data for each needed interval (for a maximum of nine intervals per diagram chart for one optical reading), such as total waiting time in an interval and total travel time in an interval. An additional alternative is the separate use of the optical reader to transform into digital numbers the data on the diagram charts. These data are then manually transferred to magnetic tapes for computer analysis.

STATISTICAL METHODS FOR DATA PROCESSING OF BTT

The following section deals with the quantitative aspects of the analysis of travel-time data. It should be remembered that additional managerial data can be obtained from the tachograph diagram chart. However, this paper is focused only on travel time (BTT), which is a most vital factor in scheduling buses to trips.

Outline of Methods

The main objective of data processing is to create a data base on bus travel times for different cross sections of the day, the week, and the season. In other words, one is interested in obtaining mean values and standard deviations for $BTT_{i,j,k}$, where i, j, and k are indexes for indicating daily, weekly, and seasonal divisions, respectively.

It is clear that the number of values of i,j,k will affect the size of the memory needed for storage of data in the computer. The values of $BTT_{i,j,k}$ will aid the planner in bus work schedules, both with the Gantt charts and with the interactive system between man and computer.

In discussing a bus system of the size of Egged (4000 lines), an approach based on the total values of $BTT_{i,j,k}$ for each line, or for a group of lines with similar characteristics, is needed. For this purpose, a systematic method for data processing was built on a wide-ranging sample basis. These data will be collected by use of the tachograph (or, alternatively, at the origin and destination points of each bus line, a method that will require large manpower resources).

Figure 2. Flowchart of procedures for determining BTT values.

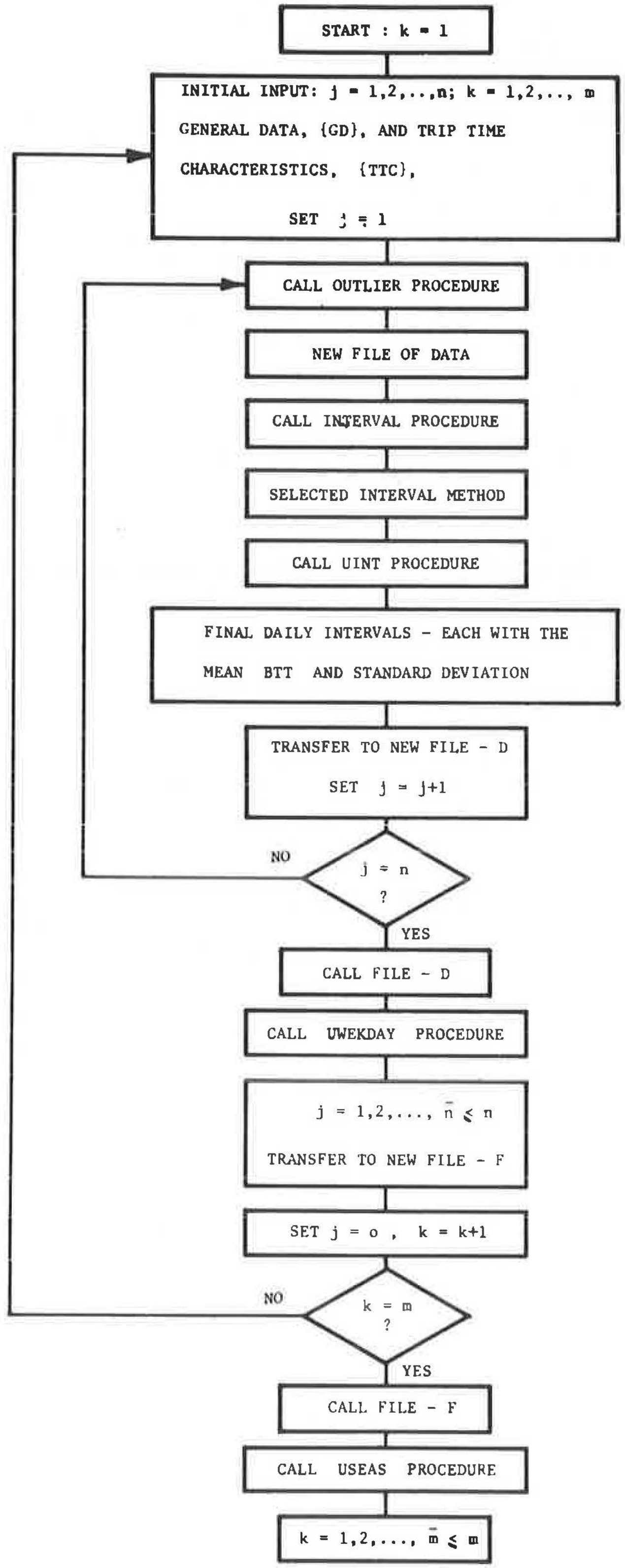
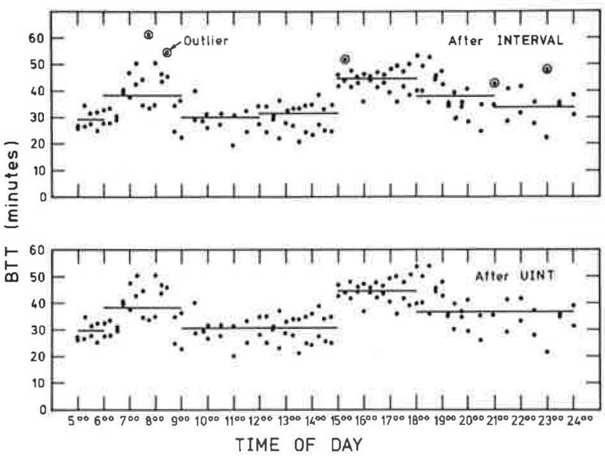


Figure 3. Example of BTT data points for a bus line with means determined by the INTERVAL and UINT procedures.



From a statistical viewpoint, if there exists a large data bank that can be systematically updated, an analysis of variance can be carried out (based on the normality distribution assumption) in order to estimate the effects of i,j,k, the independent variables, on the dependent variable BTT. Afterwards, an analysis of the independent variables that were found to affect the dependent variable (at a desired level of significance) can be carried out by the use of contrasts. Finally, it is possible to apply multiple variable regression of the model.

In order to effectively carry out an analysis of variance on i,j,k, a data bank must be accumulated over a yearly period on the assumption that there were no physical changes along the bus route or in the location or quantity of bus stops. Since it is well known that bus lines are liable to physical changes in a dynamic way, it is questionable whether the data bank for BTT values can rely on a yearly base. More than this, it is desirable that the process that determines the relation of $BTT_{i,j,k}$ al-

Figure 4. Record of OUTLIER, INTERVAL, and UINT procedures for Figure 3 example.

```
NEXT SET FOR BUS        1   IN DAY  30  FROM  HAIFA        TO  HEDERA

          *OUTLIERS
1     7H   45M    62.00
1     8H   30M    55.00
1    15H   15M    51.00        TOTAL(INPUT) NUMBER OF BUSES: 126
1    21H    0M    44.00
1    23H    0M    49.00        NUMBER OF BUSES WITHOUT OUTLIERS: 121


           F-TEST & T-TEST FOR GIVEN SET OF BUSES
           ======================================

      FIRST STEP - F-TEST TO ACCEPT THE METHOD FOR
   DIVISION OF INTERVALS DUE TO BTT (BUS TRAVEL TIME).

              THE SIGNS FOR METHODS :
              -----------------------

              A-BY ONE HOUR
              B-BY TWO HOURS
              C-BY THREE HOURS
              D-THE WHOLE DAY
```

COMPARISION		F-CALCULATED	F-TABLE	CONCLUSION
A	D	1.9229	1.35*	CONTINUE
A	C	1.1502	1.35	C ACCEPTED

```
THE ACCEPTED METHOD OF DIVISION TO INTERVALS IS  C

      NEXT STEP - T-TEST BETWEEN THE INTERVALS OF THIS METHOD


              THE TOTAL RESULT AFTER T-TEST IS:
              =================================
```

INTEGER INTERVAL	ACTUAL INTERVAL	MEAN	ST.DEV.	NUMBER OF BUSES
5:00<T<= 6:00	5: 0 6: 0	29.40	3.5022	10
6:00<T<= 9:00	6:15 9: 0	38.18	8.0688	22
9:00<T<=15:00	9:30 15: 0	30.86	6.0802	36
15:00<T<=18:00	15:15 18: 0	44.74	4.5447	23
18:00<T<=24:00	18:15 24: 0	36.93	6.9829	30

low for intermediate involvement of those responsible for data collection. This involvement can be expressed by the identification of outliers whose cause is known and by practical decisions relating to changes in the statistical criteria (which are combined in the process) in relation to different bus lines.

As a result, it was decided to base the method for determining BTT values on a number of criteria for characterizing outliers--for division of the day into time used, for division of the week into homogeneous days, and for division of the year into seasons. If there are no physical changes for a given bus line over a yearly period, and a data bank for BTT values exists, there is a possibility of carrying out analysis of variance and contrasts for i,j,k. In addition, it should be remembered that the objective is not to build a statistical model for simulation or control but to build a value system for $BTT_{i,j,k}$, which can be of greater aid in realistic planning than a single mean value for all days of the year (such as that currently used by Egged).

The statistical method was chosen according to the following criteria: It must be simple, flexible, systematic, and practical. The method, shown in the flowchart in Figure 2, is made up of four main components:

1. Exclusion of outliers (OUTLIER procedure),
2. Division of day into intervals (INTERVAL procedure),
3. Union of intervals (UINT procedure), and
4. Union of days for weekly and seasonal cross sections (UWEKDAY-USEAS procedure).

The first three components relate to the data on a daily basis, and the fourth component serves as a tool for determining the division of j and k.

Figure 2 describes the course of the method. At the onset, data are assembled into two sets: (a) general data (GT), which include the number of buses in the set, bus-line number, origin, destination, the day (or days) of the week, and the season, and (b) specific data (TCC), which include bus departure time (exact hour and minute), bus travel time, and type of bus. The outliers are deleted from these data, and then a number of methods are tested for dividing the day into intervals (division for each hour, each 2 h, each 3 h, and one daily average). After the suitable method has been chosen (in relation to a statistical criterion), statistical tests are carried out to determine the possibility of unifying the intervals according to the chosen method. The procedure continues for the series of days j, and then the possibility of unifying the days (which are characterized by various indices of j) is examined. The next step examines the possibility of unifying a number of days from different seasons; this is possible if the division of days j in each season (or at least those chosen for unification) is similar. The procedure is described in detail in the complete report by Ceder (11).

Example of a Data Set

A PL/1 program has been written for all procedures shown in Figure 2. This program is in partial use in the following example, which considers a single day.

For a given bus line departing at a frequency of either every 15 or every 30 min, data were collected for two days (the same day for two weeks) at a total of 126 data points (see Figure 3). In the OUTLIER procedure, five outliers were found; these are marked in the upper portion of Figure 3 and also appear at the start of Figure 4, which is a computer record.

Following a run of the INTERVAL procedure, method C was chosen--that is, a division of the day into 3-h intervals, where the first hour is considered separately, as shown in the upper portion of Figure 3 and in Figure 4. The data then proceeded to the UINT procedure. Of the seven intervals in method C, two are united and only five intervals remain, as shown in the lower portion of Figure 3 and in Figure 4. This example does not include the UWEKDAY-USEAS procedure.

The last five intervals (each with a mean and standard deviation) are transferred to the planner for bus work schedules. This transfer can be made either automatically or manually. Determination of the BTT value for planning purposes will depend on the degree of certainty desired regarding the bus's arrival at its destination prior to or at the planned time. For this purpose, the mean is accompanied by a standard deviation value.

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