AUTOMATION IN SCHEDULING FOR TRANSIT OPERATORS

by

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SYMBOLS AND THEIR DEFINITIONS

Symbol	Meaning	Definition
P. W.	Piece of work	A piece of work is an amount of work, in an operator's assignment, which pays less than eight hours.
St. Run	Straight run	A straight run is composed of continuous hours of pay, at least 8.00 hours from "on duty" time to the "off duty" time.
St. Run No.	Straight run number	A straight run number is a specific straight run designated by a specific number.
Sp. Run	Split run	A split run is composed of at least 8.00 hours, with an unpaid interval or intervals between its pieces of work.
Sp. Run No.	Split run number	A split run number is a specific split run designated by a specific number.
Wo. Ti.	Working time	Working time is the time the operator is actually operating the bus.
R. Ti.	Report time	Report time is a specific amount of time allowance, (10 minutes) an operator receives at the end of each run and piece of work during his assignment.
To. Ti.	Total time	The total time for which the operator is paid (could include report time, penalty time, or overtime).
Spd. Ti.	Spread time	Spread time is the total working time plus the unpaid time of split run.
Sch. No.	Schedule number	Schedule number is a specific number designated for a bus that goes over a specific route at a certain time.

SYMBOLS AND THEIR DEFINITIONS (CONT.)

Symbol	Meaning	Definition
P. Out	Pull out	Pull out is the starting time of a piece of work, straight run, split run, or a schedule number.
P. In	Pull-in	Pull-in is the finishing time of a piece of work, straight run, split run, in a schedule number.
Rel. Pt.	Relief point	Relief point is a specific location or locations on each route where operators may be relieved or assigned to the bus.
Term. T.	Terminal time	Terminal time is the time required to drive between the garage and the first relief point.
Rl. 1	Relief 1	Relief 1 is the time between first and second relief points.
Rl. 2	Relief 2	Relief 2 is the time between second and back to first relief points.

INTRODUCTION

History and Development of Transportation Methods

Transit system has been the dominant force in shaping the nation's cities for years. It was not until an adequate network of roads usable under all weather conditions was made available that buses could provide really satisfactory service. In 1890, there were only about 100,000 miles of all weather roads in the United States. Mechanized urban transportation, which began its development in the early 1900's, enabled cities to grow to almost any extent that man could manage. Until the later part of the 1920's, the street car was the major vehicle of mass transportation, carrying 12 to 13 billion passengers annually. The rapid transit operations have remained at fairly even level for half a century, but favorable trend for bus transportation rose up to 72.6 per cent in 1954 from 16 per cent in 1930.[1] The shifts in public sector of transport system from rail to bus resulted due to various reasons such as: (1) route flexibility to cover widely dispersed origins and destinations of traffic resulted from the growth of urban area; (2) individual power supply; (3) ability to pass each other freely; (4) through service to off-route locations; (5) ability to combine routes with one vehicle rendering the service; (6) low initial cost; (7) ease of providing some satisfactory headways; (8) requires only moderate

[1]Wilfred Owen, The Metropolitan Transportation Problem, The Brookings Institution, 1956, p. 76.

density of population to find profitable roads compared to rails; and (9) curb discharge.

The number of transit riders reached a peak in 1945, the last year that automobiles were hard to get. The boom in ownership of private automobiles due to post-war economy resulted in more trips by automobiles, with decrease in public transit riders. Since then, each year the transit volume dropped until 1950 when the volume was equivalent to that of the mid-1920's. Since 1950 transit volume has dropped even further, to the point where Americans now spend only $1.5 billion per year on public transit and rail commuting, compared to $1.8 billion in 1929.[2] During the same period automobile expenditures have increased from $11 billion to $27 billion, and approximately one-half that amount is spent on driving within cities. The long range growth rate of new cars has been rising about 2.8 per cent a year on the average since 1950. The forecast is that new car sales will rise to 7.5 million by 1965, to 8.6 million by 1970, and 10 million by 1975.[3] These trends in transportation are represented graphically in Fig. 1, page 3.

This revolutionary change in transportation since 1930 has left public transit companies in the worst crisis.

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[2] The editors of Fortune, The Exploding Metropolis, New York, 1957, p. 34.

[3] Peter Edson, Nation Seen in Wake of Car Industry Boom, Newspaper Enterprise Assn., Washington, 1963.

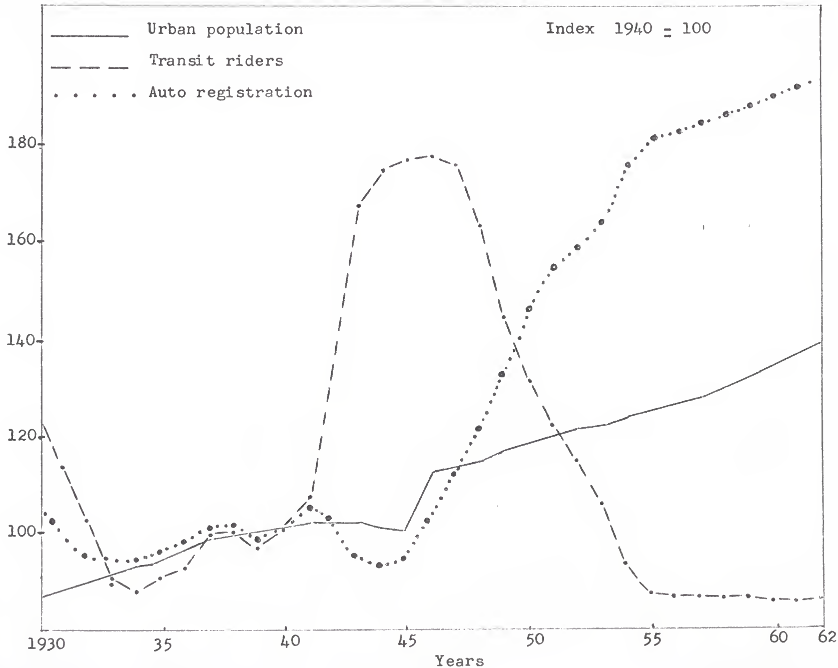

Fig. 1. Trends in Transportation.

Factors Currently Affecting Bus Transit Systems

The shift from public transportation to private automobiles is due to the increased production and general prosperity of the post-war boom and expansion of the metropolitan area together with the population growth. Another cause is gradual shift of population centers from the city to the surrounding expanding suburbs. This shift is accompanied by the displacement of industrial, shopping, and commercial activities from central business district (C.B.D.) to suburbs, thus decreasing the necessity for resorting to the "downtown area" consumer needs.

An increase in the number of families with two cars and creation of the "car pool" has allowed the housewife to use the family car for her needs rather than the bus.

Increased traffic congestion, due to the ever increasing number of automobiles, has caused a greater expenditure of fuel and labor time in the bus industry without any corresponding increase in passenger revenues due to labor fringe benefits and sizable wage increase in the inflationary period. Today the bus transportation is facing its worst crisis. During the past several years, 229 transit companies have abandoned operations, and 120 cities have been left without transit services.[4] For many other companies rising total costs and declining patronage made it impossible to make both ends meet for transit operations.

The present situation of public transit has not only posed

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[4]Owen, op. cit., p. 94.

problems for transit organizations, but also for the city planners, who are continually attempting to make the city a center of social, culture, and business activities. City planners are confused as to how to provide for the flow of people in and out of the heart of the city.

Urban Transportation Planning

Inability to cope with mounting motor vehicle traffic and growing inadequacies of mass transportation have stimulated a wide variety of joint efforts of federal, state, and local governments for construction of expressways, the establishment of authorities to provide high cost bridges and tunnels, the use of special agencies for the provision of parking and terminal facilities, and the modernization and organization of public carriers. Suitable systems would reduce traffic congestion which in itself would be a boon to bus transit. City planners, however, do not all agree. They argue that even after modernization, up to what extent will autos be feasible in limited land for parking and terminal facilities? The limited lanes of expressways is not the solution; they will soon be flooded again causing the same crisis.

In summary, some city planners feel that public transit must be utilized on a much larger scale, or the city will no longer be the center of activity in metropolitan area. If congestion continues, it is feared that the public will resort to shopping in suburban centers abandoning the city. More people can be handled more efficiently by bus, trolley, or commuter train on developing central core of the city. This makes planners believe that unless the public transit is vastly improved and patronized, the city will cease to exist as we know it today.

The Hypothesis

Varieties of research have been carried out for the solution of this crisis, but time will be required for the validity of the results. Meanwhile, with the hopeful outlook, public transit companies must seek an immediate solution to stay in business long enough to be profitable.

Reduction in operating cost by rescheduling has been the aim of such companies to maintain them profitably. However, to keep pace with changing patterns of traffic, transit companies must seek a method of quick and efficient rescheduling to maintain effective service. Aforementioned capacity can be acquired by high speed electronic computers. The use of I.B.M. 1620 electronic computer is proposed as an aid to solve the transit operator assignment problem, by the elimination of the present lengthy calculations.

DIVISION OF THE SCHEDULING PROBLEM

Out of the United States' sixty-six million work force, only ten million commute. In spite of this the journey to work passenger volume is larger on week days than any other type of week-day travel. Six million of them get to work and back by automobiles, one-half million by rail, and three and a half million by bus, subway, or rapid transit. The bus system is the major transportation mode in many cities, while in others, bus has to compete with rail, subway system, and taxies. The inter-city bus operation is essential to link thousands of scattered communities by forming an integral part of the passenger transportation system. Buses in transit operations are adopted due to various reasons as mentioned before.

The city bus transit system is usually divided into routes. A route is the street or series of streets that the bus follows in order to move between one point of origin and the other a destination; two specified locations--usually between central business district and a residential suburb. A route may have any number of branches, turn-backs, loops, and end terminals (Fig. 2, page 8). On each route there will usually be many schedule numbers. A schedule number is a bus that goes over a specific route at a certain predetermined time.

Operational Factors in Scheduling

Various operational factors sometimes present problems for scheduling bus operators' assignments. The public transit industry is subject to traffic peaks of rush hours of early morning

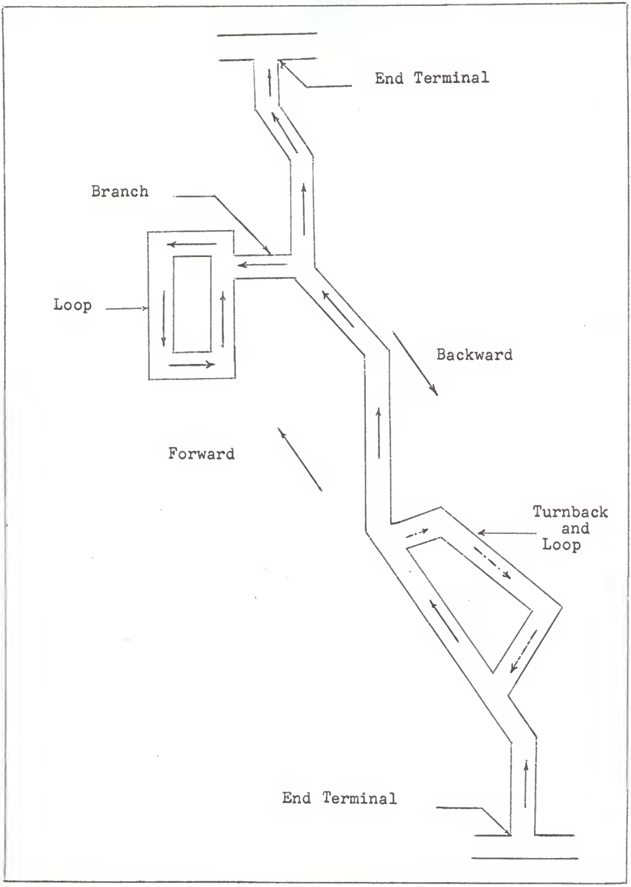
End Terminal
Branch
Loop
Backward
Forward
Turnback
and
Loop
End Terminal

Fig. 2. A Route.

and late evening. During the peak hour rush about 90% of the commuters travel by public carriers, while only about 10% movement is by automobile or taxi. In contrast to this, on Saturday public transit patronage is only about 74%, and on Sunday the load is only 38% of the weekday average. This pattern of passenger movement means that the transit companies must still maintain the high manpower and equipment requirement to encounter the needs of peak hours despite the overall reduction in number of passengers accommodated throughout the day. Much of this equipment is idle during the off-peak period, and the working force that must be employed for a few hours to handle the peak must be paid for a full day. Thus, the peak periods add difficulties in scheduling. During the peak period the schedule may call for a transit vehicle over a particular route every two or three minutes, while during the off-peak period after ten, fifteen minutes or less time interval may be adequate. In addition to bus allocation problems, this demands a certain amount of split shifts for operators who may work, for example, four hours in the morning, with three hours off, and again four hours in the afternoon. Splitting of shifts has always been a matter of contention between the transit management and employees labor union with the latter's demand for the extra compensation for the dead time--time between shifts.

Increased traffic congestion during rush hour has caused a greater expenditure of fuel and labor time and a deterioration in service for customers. Express runs as an effective means for cutting down the number of stops, and hence running time, has been suggested quite often; but the income from such express run is often low.[1]

Taxes have also been an added burden for the transit industry. In previous years when transit enjoyed a monopoly of local transportation, the municipality required the payment of franchise taxes for the privilege of using the streets. In most cases these taxes are still levied despite the highly competitive conditions to which the transit industry is subject.

The route flexibility to cover widely dispersed origins and destinations of traffic resulted in increased number of requests for additional routing and rerouting for scattered suburban areas, even though the load potential for such routes is limited for return revenue. Thus, along with the profitable route, the transit industry must also cope with unprofitable routes due to the pressure of public petitions and regulations of public utility commissions. However, the transit companies at the same time also realize that if a real efficient schedule is set up, it would offer one of the greatest possibilities for possible transit operation. The whole problem of scheduling is customarily divided as follows:

(1) Partitioning the city or town into zones and determining the passenger load, and hence, the vehicle requirements (number of buses needed per route).

(2) Establishment of headways, i.e., the time in minutes between vehicles.

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[1]Wilfred Owen, The Metropolitan Transportation Problem, The Brookings Institution, 1956, p. 94.

(3) Run assignments for operators, i.e., the allotment of daily work.

Determination of Passenger Load and Vehicle Requirements

The starting point for the transit schedule maker is to obtain adequate and properly handled passenger load data for the routine adjustment of schedules to provide service in accordance with the number of people who wish to ride the system at various periods of the day, on various days of the week, and during different seasons of the year.

In order to develop efficient scheduling to provide the best necessary service with the least amount of equipment and manpower, it is the general practice of the transit industry to check the routes for the record of passenger count by trained traffic personnel, around the clock for a given period, until all the routes are checked for the information. Transit passenger loads are observed and recorded at predetermined points where the heaviest loads occur, such as the strategic points like turn-back locations, branching and transfer points.

The checkers are assigned to predetermined points covering a route completely for the survey of passenger loading data.[2]

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[2]"A mechanical device has been patented, which will improve on the manual traffic checking. This portable recorder produces, on tape, time of day and a passenger on-and-off count for each vehicle operated; also totals the accumulation of riders at designated locations. These recordings on the tapes will be fed directly from the vehicle checked to an electronic interpreter." From a speech to the American Marketing Association by J. T. Harman, Scheduling Mass Transportation Vehicles Electronically, (Feb. 20, 1958).

Some specific recordings are necessary to summarize the pertaining information as follows:

(1) Trip origins and destinations

(2) Purpose of trip

(3) Establishment at destination

(4) Time of vehicle

(5) Number of blocks walked

(6) Mode of travel

(7) Number of passengers on each vehicle

(8) Weather conditions.

The techniques and details of data collection will vary to the size of the community and the use to be made of the information.

When a load factor, the total number of seats plus standing spaces per vehicle, is divided by the passenger load, the number of passengers on a particular route per hour, the result will be the number of vehicles required per hour per route.

Establishment of Headways

Headway is the average interval of time, in minutes, between individual vehicles moving in the same traffic lane, measured from head to head as they pass a given point. This, in turn, determines the spacing of the vehicles (Schedule numbers). In order to move vehicles from terminal to terminal on an evenly-spaced headway, proper running time must be provided. The running time is the time required to travel between two points on a route. No schedule could operate effectively or without loss of manpower unless it had the proper running time. The transit schedule maker must estimate the most adequate running time required for the sake of public convenience and economy of operation. If running time is much more, then there would also be a poor performance, since it would force retardation of other following vehicles or else run ahead of schedule and cause uneven spaces in the headway. When an operator runs ahead of schedule, he forces the next operator to be late, since more passengers would be waiting for service than ordinarily. Thus, the running time must be determined in order that an operator can service his passengers safely and adequately, assuring them the dependability of the performance of the transit service.

Running time is compiled through time studies made under actual operating conditions to record travel time and speeds. The resulting information can be applied to new schedules, so that proper time is allocated to each series of trips, providing maximum operating speed with safety. Further, the adherence to the schedule is checked by intermediate points spaced approximately at equal distance along the route.

The daily operated mileage per vehicle provides the service control for the maintenance department, while man-hours scheduled become the basis for payroll accounting.

The man hours scheduled are then broken down for work assignment for each operation; the result is called a run.

Run Assignments for Operators

The difficulty encountered in assigning everyday runs for bus operators is experienced due to many variables. Both operating variations in time per trip and the labor union contract restrictions are responsible for the situation.

The trip length variations result in difficulty in arranging runs, because they must be broken or combined into time segments, within the labor union restrictions.

The labor union contracts often include the following:

(1) Regular runs must pay a specified number of hours (normally eight hours).

(2) If a run is less than eight hours, unworked time is added as a penalty.

(3) Preparation and storage time allowance.

(4) Travel time allowance.

(5) Report time allowance.

(6) Spread penalty for constructing a run beyond a certain number of hours (say thirteen hours).

(7) Overtime premium after a basic eight hour work at the rate of time and a half.

(8) Minimum length of piece of work.

(9) Minimum requirements of straight and split runs.

The above-mentioned makes the manual scheduling technique tedious and complicated. Reduction in operating cost, by rescheduling, has been one of the objectives of transit companies to maintain operations on a profitable scale. Reduction in operating cost can play an important role, but if such reduction is pushed too far, it will bring the deterioration in service and, hence, another decline in passenger revenue. The high speed electronic computers, however, can furnish efficient and quick scheduling techniques by avoiding tediousness and complexity to the manual method.

Previous studies had been conducted on both (1) determination of passenger load and vehicle requirements and (2) establishment of headways elsewhere. Run assignments for operators, the third phase of the scheduling problem, will be discussed further in the following sections.

PRESENT SCHEDULING TECHNIQUE OF A COMPANY

When any company moves into a city to operate a bus line, it does so either by taking over from another existing firm or by starting as a new concern. In either case, the decision pertaining to the routes on which the company will operate is finally dependent upon an agreement between the city planning commission and the company, after studying existing factual information regarding: (1) street use, (2) origin, destination, and land use, (3) existing level of traffic service, (4) existing level of transit service, (5) inventory of the physical street system, and (6) financial reports and records. Changes in the form of addition or deletion of existing routes would be made after a careful study of existing facts for the present and potential need for future of the city residents, and the economics of serving for this need.

The passenger load for public transportation is estimated by the aid of questionnaire or personal interview, by collecting the information, such as the geographical location of trip origins and destinations, time of start and end, purpose of trip, number of trips, mode of travel, kind of work, type of industry, the nearby industries, etc. The best estimate, however, is based upon skill and experience rather than any formal or analytical techniques. The number of buses needed per route for a particular zone can be obtained by dividing the expected number of passengers by a load factor which depends on the capacity of the buses. Ordinarily, during traffic peaks of rush hour a greater number of buses, as many as three or four times, is required than during the normal service periods.

The next step is the establishment of the round trip mileage and headways for each route for the efficient scheduling. The round trip time is obtained by dividing the mileage of trip by the average speed of the bus, which is usually about 12 or 13 m.p.h. for the specific route. The headway--the time interval in minutes between two vehicles on a specific route--can be established either by dividing round trip time by the number of buses or by some related assumption. The headway during the rush periods is always less than one-half to one-third that of the normal headways.

When passenger load information is summarized, present capacities and time schedules of transit vehicles are analyzed for the adjustment of schedules to a level of adequate service. For example, if some passengers wish to be at work, say at 6:00 A.M., then the first bus must arrive there at 5:50. (5:50 indicates 5 hours and 50 minutes, and 5.50 indicates 5 and 50/100 hours. These notions are also adopted elsewhere in this report.) If the headway is twelve minutes, then the second bus would be due at 6:02, and the next at 6:14, and so on.

If eight buses are needed to carry passengers to the downtown area during the evening rush hour period, then by knowing the arrival time, round trip time, and headways, the pull-out times from garage can be calculated. This will determine the service frequency and regularity of the schedule. The following example will clarify this further. Assume that on a certain route these data apply:

(1) Late evening rush period is until 6:30 P.M.,

(2) Round trip is one hour,

(3) The desired headway is 10 minutes,

Then (4) Six buses are needed for downtown between 5:30 P.M. and 6:30 P.M.

The timing points on this route are indicated. The scheduling is simplified by including two round trips on the same paper. Now, if on route "R" the timing points are Market Street, N_1, N_2, and N_3, then it is indicated as follows:

Pull-out	Market St.	N_1	N_2	N_3	Market St.	N_1	N_2	N_3		Market St.
										530
										540
										550
										600
										610
									(10)	620

Notice the headway is 10 minutes for this route.

To calculate the pull-out times of the buses to determine when they will leave the garage, the following data are obtained:

Sch. No.	Pull out	Market St.	N_1	N_2	N_3	Market St.	N_1	N_2	N_3	Market St.
1	325	330	345	400	415	430	445	500	515	530
2	335	340	355	410	425	440	455	510	525	540
3	345	350	405	420	435	450	505	520	535	550
4	355	400	415	430	445	500	515	530	545	600
5	405	410	425	440	455	510	525	540	555	610
6	415	420	435	450	505	520	535	550	605	620

5:20-4:20 = 1 hour | 6:20-5:20 = 1 hour

Notice that the time for a round trip is one hour. Each one of these buses is given a number called the schedule number as shown above.

All the aforementioned steps will be repeated for the normal service periods, the headway time will be greater, and thus, lesser number of buses will be required. The buses not required either have to be assigned to another route or sent back to the garage.

Applying this to the above example with previous assumptions of:

(1) Late evening rush period is until 6:30 P.M.

(2) The round trip time is one hour.

(3) The desired headway is 10 minutes.

Then (4) Six buses are needed for downtown between 5:30 P.M. and 6:30 P.M.

Plus the following additional assumptions:

(5) The desired normal headway is 20 minutes.

Then (6) Three buses are needed downtown after the evening rush period.

Sch. No.	Pull out	Market St.	N_1	N_2	N_3	Market St.	N_1	N_2	N_3	Market St.	Pull in
1	325	330	345	400	415	430	445	500	515	530	
2	335	340	355	410	425	440	455	510	525	540	545
3	345	350	405	420	435	450	505	520	535	550	
4	355	400	415	430	445	500	515	530	545	600	605
5	405	410	425	440	455	510	525	540	555	610	
6	415	420	435	450	505	520	535	550	605	620	625
1		530	545	600	615	630	645	700	715	730	
3		550	605	620	635	650	705	715	735	750	
5		610	625	640	655	710	725	740	755	810	

This will continue until late night when less buses have to be inserted in the schedule with the proper headway time. After this period is over, service returns to early morning rush, and normal period. This route is customarily rescheduled specially for Saturdays and Sundays, due to considerable reduction in travel load. The technique of this example is utilized for actual scheduling of operators, run assignment.

The last and probably the most difficult step in completing the schedule is to determine runs, i.e., the individual operator assignment to a specific bus on a specific route. This step is partially restricted by the variation in run and the labor union contract. The labor union contract, say with Company "A", is as follows:

(1) A straight run is constructed to be composed of continuous hours of pay (at least 8 hours).

(2) All runs pay minimum 8 hours. Penalty cost, at regular rate, for a run less than 8 hours is paid.

(3) Of all the runs, at least 35% straight runs and most 65% split runs.

(4) Overtime work is defined as work in excess of 8 hours and 50 minutes, in case of a straight, and 9 hours in case of a split run.

(5) All overtime work is paid at time and a half of a regular pay.

(6) A piece of work should pay at least 2 hours unless it is on the extra board; then it should pay 2 hours and 30 minutes (every piece of work has a 10 minute report time).

(7) After each run an operator is given 10 minutes for report time.

The ideal schedule for a company would be one with all straight runs, since it costs less and is preferred by employees. However, the variation in service trip length makes it practically impossible, due to the inconvenience in relieving the driver at night, if he is on a split run. It is preferred that all split runs be scheduled during the day time.

At present transit company "A" schedules each route independently as follows:

(1) Scheduling department finds the total time for each bus (scheduling number) in service, and the time it pulls out and pulls in to the garage, from the schedule (time table or the "board" as it is sometimes known).

(2) These service times, depending on their length, are divided into eight hours of work by trial and error method.

(3) Although Step 2 is carried out by trial and error method, the following two rules may be used as a guide to schedule pieces of work:

a. Pieces of work are easier to schedule into split runs if they are about four hours in length.

b. Each route should be balanced separately. This requires equal number of A.M. pieces of work and P.M. pieces of work to construct split runs.

(4) After the time-table or "board" is broken into eight hour straight runs and pieces of work, split runs are constructed by combining A.M. and P.M. pieces of work in order of occurrence. This will take care of most of

them leaving some still unscheduled, since they do not fit well together in split runs.

(5) At this point the percentage of straight runs to split is checked. If the number of straight runs is over 35% (which it usually is), then some of the work straight runs will be broken in pieces of work to construct split runs with unscheduled pieces of work.

(6) Any pieces of work then left unscheduled are added to the extra board. The extra board schedule is constructed on a daily basis, and a sufficient number of employees is hired to take care of the unscheduled pieces of work, employees' leave of absences, vacations, sickness, etc.

The problem of scheduling bus operators' assignments can best be solved by electronic computers. This can be done by following the above-mentioned manual pattern very closely.

COMPUTER TECHNIQUES FOR TRANSIT OPERATOR'S ASSIGNMENT

In our dynamic economy the role of data collection has been increasing in importance ever since the conception of such scientific management tools as data processing and electronic computers. The scientific approach to the solution of management problems has changed the whole concept of management decision making--more analytical by the aid of high-speed computors instead of empirical or trial-and-error manual methods.

Though these electronic computers are costly, their service can be available from the computer service organization on the hourly basis by the small business organization. Their use is based on the ability to perform millions of calculations with great speed, to produce accurate results, to store large quantities of information, and to carry out long and complex sequences of operations without human intervention in relatively very small time than by the manual methods.

Typical Applications

Electronic computers today are widely used to assist in solving the problems of science, engineering, and business. They are used in connection with the design of equipment, in evaluating the results of tests and experiments, in controlling process, in keeping records of many types, and in a wide variety of applications involving the processing of business data.

Managerial work includes job reporting, payroll, accounting, labor distribution, inventory control, sales statistics, and numerous varieties of scheduling problems.

For example, for the automation of traffic assignment, the factors to be considered are origin and destination of the trip, mode of travel, purpose of the trip, number of trips, passenger load, total trips, weather conditions, population, and load capacities. It has been estimated that roughly 25 million computations would be required for this test. On a very optimistic basis, if one computation can be completed in ten seconds by ordinary desk calculators, it requires some 30 man-years for completion. However, with electronic computers, using cards input and output and with tape, the time required is reduced enormously to only about ten hours or less computer time.[1] Thus without computer such a complex problem would have been unsolved for years, and urban transportation planning would have faced its worst crisis.

Along with the use of new facilities, this means a new level of expenditures. Hence, the problem must be studied carefully in order to determine if it is complex and lengthy enough for the computer aid and still is economical. Once this criterion is met, however, the results are impressive.

Thus, the problem of scheduling bus operators' assignments, especially for the widely spreading large urban areas, can best be solved with computer techniques. The problem arises mainly from the ever-changing traffic patterns (due to change in traffic equilibrium for the peak hour rush), according to Parkinson's Law,[2]

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[1]G. E. Brokke and W. L. Mertz, Evaluating Trip Forecasting Methods with an Electronic Computer, Travel Characteristics in Urban Area, H.R.B. Bulletin 203, 1958, p. 59.

[2]C. Northcote Parkinson, The Loss and the Profits, publ. Houghton-Mifflin, Boston, 1960.

and the restrictions which arise from the labor union's contract and the city planning and traffic commissioners' regulations placed on the operating company.

The hourly wage rate for drivers averages about 3.50 dollars, while the variable operating cost for a bus approximates 11.20 cents per mile or 1.46 dollars per hour (thirteen m.p.h.).[3] This ratio of driver to bus operation cost is about 2.4 to 1 and emphasizes the need for efficient scheduling.

The program described in this report is designed to be processed on the I.B.M. 1620. Once this program is prepared, the speed and accuracy of the computer permits the scheduler to attain results without a single error attributable to the computer, by eliminating clerical work and endless hours of calculations. The program is developed to follow the old manual pattern of scheduling very closely, by the aid of the computer language which is comprised of a number of statements. By using a logical model for each line, the computer follows each bus across its own route, making high-speed decisions and calculations on the basis of data supplied. Various restrictions, such as maximum hours of work limit, penalty and overtime premium, and points on the route where decision must be made, are pre-established.

The Program

The main object of this assignment program is to construct a

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[3]National Association of Motor Bus Owners, Bus Facts, Washington, D. C., 1963, p. 36-38.

schedule with as many straight runs as possible and with a minimum number of unscheduled pieces of work such that the overall operating cost can be optimized.

This program is developed using FORMULA TRANSLATION-FORTRAN system. FORTRAN language for the I.B.M. 1620 and the other recent I.B.M. computers is an automatic coding system that closely resembles the language of mathematics.

FORTRAN system consists of FORTRAN language and FORTRAN processor. FORTRAN language is comprised of a number of statements that the programmer may use in coding the problem to be solved. A program written in the FORTRAN language is known as the source program as inputs and produces, as output, a machine language program, the OBJECT PROGRAM, that is ready to run on the 1620 I.B.M. computer. The programmer need concern himself with only FORTRAN language, since the processing of the source program is completely automatic.

Due to its complexity, the typical run cutting problems for assignments may be divided in four sections such that output of one section is input of the succeeding one.

Section I. Straight runs are constructed by knowing the pull-out times and pull-in times of all the schedule numbers on a route.

Section II. Split runs are formed by combining pieces of work.

Section III. Split runs are constructed by breaking the straight runs (Section I-A) and combining these pieces of work with those pieces of work that were not scheduled in Section II.

Section IV. Find the total cost of a schedule. This report is concerned only with section I*.

The description of program for this section is in the following order:

1. Presentation
   a. Assumptions
   b. Flow diagram
   c. Discussion
2. Preparation of data
3. Example and remarks
   (For the computer solution see Appendix.)

Method of Straight Run Cutting

Straight runs are developed by knowing the pull-out time and pull-in time of all the schedule numbers on a route.

1. Presentation
   a. Assumptions
      The following assumptions are included in the source program:
      (1) Assumption No. 1
         (a) A straight run should pay at least eight hours.
         (b) The operator gets ten minutes for the report time at the end of each run.
         (c) Thus, a straight run can be composed as follows:

---

*Dr. Samy E. G. Elias, The Digital Computer Solution to the Transit Operation Assignment Problem, Thesis for Doctor of Philosophy degree, 1960. Reference for other sections.

7.83	Work time
.17	Report time
8.00	Total

(2) Assumption No. 2

(a) Overtime is the work in excess of eight hours fifty minutes.

8.67	Work time
.17	Report time
8.84	Total (= 8:50)

(b) Overtime premium is one and one-half times the regular rate.

(3) Assumption No. 3

The terminal time, relief time 1, and relief time 2 are known. Assumption is included in the form of in-put data, since this makes it simple for any change to suit any specific case without any damage to the source program.

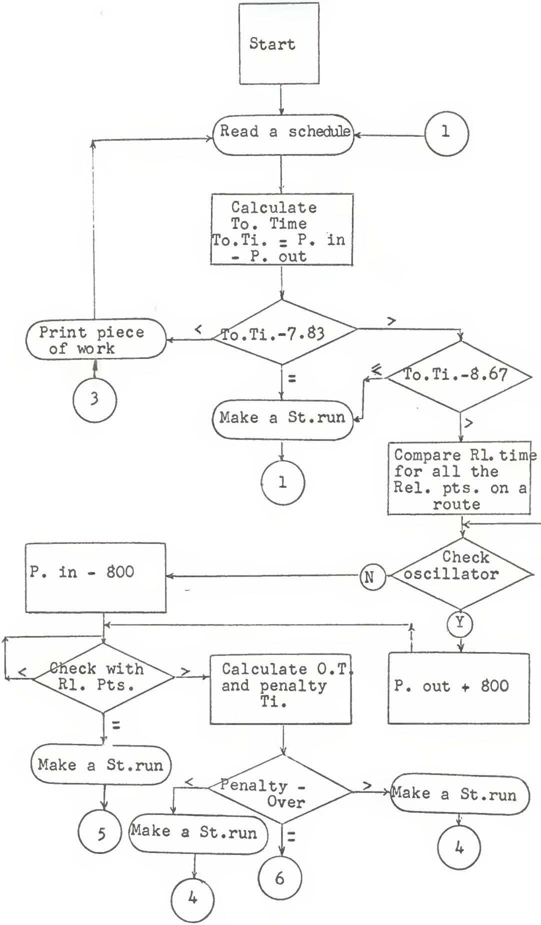
b. Flow diagram (See Fig. 3, page 29).

c. Discussion

The program is designed using "FORTRAN" language such that the machine will do the following:

(1) The machine will read one card (data card information regarding schedule number, route number, pull-out time, pull-in time, relief time, and terminal time) at a time from the reader's hopper and will compute the total time for the schedule number and compare it with 7.83 hours, the minimum working time to make a straight run.

(2) If the total time is less than 7.83 hours, the machine


Start
Read a schedule
1
Calculate To. Time To.Ti. = P. in - P. out
To.Ti.-7.83
<
>
=
Print piece of work
3
To.Ti.-8.67
≤
>
Make a St.run
1
Compare Rl. time for all the Rel. pts. on a route
2
Check oscillator
N
Y
P. in - 800
P. out + 800
Check with Rl. Pts.
<
>
=
Calculate O.T. and penalty Ti.
Make a St.run
5
Penalty - Over
<
>
=
Make a St.run
4
6
Make a St.run
4

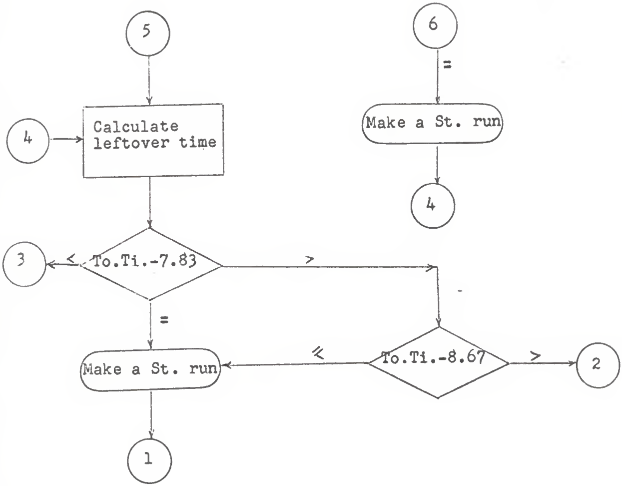


Fig. 3. Flow diagram to make straight runs.

prints it as a piece of work since no straight runs can be developed.

(3) If the total time is exactly equal to 7.83 hours, this means that a straight run can be constructed from this schedule number; therefore, the machine will add 0.17 hour for report time and print it as a straight run from this schedule number.

(4) If the total time is greater than 7.83 hours, the machine will check further comparing the time with 8.67 hours (the maximum working time before paying overtime premium).

(5) If the total time is less than or equal to 8.67 hours, this means that a straight run can be constructed from this schedule number without paying any overtime premium; therefore, the machine will add 1.17 hours for report time and print it as a straight run on this schedule number.

(6) If the total time is greater than 8.67 hours, this means that a straight run can be constructed, and still more work is available to schedule from this schedule number. In this case the machine will:

  (a) Develop a list of relief time for all the relief points on this schedule number.

  (b) Pick up the relief point which will break the total time of this schedule number to exactly eight hours or the relief point just greater than eight hours.

(c) Now check the following:

1. See if the straight run is exactly eight hours.
2. See if the straight run can be constructed by comparing with relief point which is equal to or less than 8.67 hours. If there is overtime find its value.
3. Pick up the relief point which is ahead of the one chosen in 6b (i.e., one which will cause the run to be less than eight hours) and find the penalty time.
4. Choose the most economical of the above.

(d) The machine in constructing such a straight run will work like an oscillator. If the first straight run is developed from the beginning of the schedule number, the second will be developed from the end. This is necessary to avoid being left with all pieces of work either at early morning or late night pieces, otherwise it would create a great difficulty in scheduling.

(7) At this stage, the machine will pick up the leftover work which has not been scheduled in the straight run, and run it through all the previous steps from one to six.

(8) The machine will read the next schedule number, and the previous steps are repeated.

2. Preparation of Data.

Although the program is written in floating point constants for the input data, use of an actual decimal point is optional. The data cards are punched, in fixed point constants, in the following form:

a. Columns one and two are provided for the identification of the schedule number.
b. Columns three and four are provided for the identification of the route number.
c. Columns five to eight are provided for the identification of the pull-out time of the schedule number.
d. Columns nine to twelve are provided for the identification of the pull-in time of the schedule number.
e. Columns thirteen to fifteen are provided for the identification of the Terminal time of the schedule number.
f. Columns sixteen to eighteen are provided for the identification of the relief point one.
g. Columns nineteen to twenty-one are provided for the identification of the relief point two.
h. Columns twenty-two to eighty were not used.

3. Example and Remarks.

a. Example

Input Data

Sch. No.	Route No.	P. out	P. in	Term. T.	Rl. 1	Rl. 2
13	01	0500	2113	023	045	055
14	01	0515	1113	023	045	055
16	01	0530	1765	023	045	055
18	01	0600	2114	023	045	055
28	01	1100	2315	023	045	055
30	01	1130	1330	023	045	055
32	01	0000	1213	023	045	055
34	01	0033	2050	023	045	055
36	01	1305	1605	023	045	055
39	01	1305	3605	023	045	055
40	01	1500	3006	023	045	055

Output Data

St. Run	Sch. No.	P. out	P. in	To. Ti.
** 1	13	500.	1323.	840.
** 2	13	1323.	2113.	807.
	14	515.	1113.	598.
** 3	16	953.	1765.	829.
	16	530.	953.	423.
** 4	18	600.	1423.	840.
	18	1423.	2114.	691.
** 5	28	1100.	1923.	840.
	28	1923.	2315.	392.
	30	1130.	1330.	200.
** 6	32	368.	1213.	862.
	32		368.	368.
** 7	34	33.	856.	840.
** 8	34	1201.	2050.	866.
	34	856.	1201.	345.
	36	1305.	1605.	300.
** 9	39	1305.	2128.	840.
** 10	39	2773.	3605.	849.
	39	2128.	2773.	645.
** 11	40	1500.	2323.	840.
	40	2323.	3006.	683.

b. Remarks

(1) One can notice that 0.17 hour report time is added to the working time of each straight run to get the total time.

(2) One can notice how the machine functioned as an oscillator in constructing straight run. If run is constructed at the beginning of one schedule number (as schedule No. 32), the second run is constructed from the end of the other schedule number (as schedule No. 34). This procedure will prevent having all pieces of work being either early in the morning or late at night.

(3) One can notice that for both schedule numbers 34 and 39, how straight runs and a piece of work were also constructed from the leftover working time.

(4) One can notice that for schedule number 36, piece of work was printed, as no straight run can be constructed from this schedule number.

(5) In certain cases human judgment is required, where the mechanical technique of machine has limitation. The total time for schedule number say, "i", is 7.80 hours. If 0.17 hour report time is added, the total time would be 7.97 hours. The schedule maker might find it more feasible to construct a straight run from the above schedule by paying 0.03 hour for penalty time rather than treating the schedule number as a piece of work.

(6) One can notice that for the input data for the identification of schedule number and route number, only two columns are provided.
If this capacity is not sufficient, one can change it 3 or 4 columns according to the need, just changing output FORMAT in appropriate form.

(7) Author believes that this program, in its form, is not the only way one can design it; perhaps more efficient program may be developed by proper arrangements of statements.

SUMMARY AND CONCLUSIONS

The present transportation crisis has demanded an immediate and effective solution for the survival of existing public transit companies. Reduction in operating cost, by rescheduling, has been one of the objectives of transit companies, to maintain operations on a profitable scale. The high computing speed and accuracy of the electronic computers resulted in quick and efficient rescheduling technique by avoiding manual methods of lengthy calculations.

The whole problem of transit scheduling may be subdivided as follows:

(1) Partitioning the city or town in zones with routes to serve these areas and determining the passenger load, and hence, the vehicle requirements (the number of buses needed per route).

(2) Establishment of headways; i.e., how often should the buses run?

(3) Run assignments for operators; i.e., the allotment of daily work.

The part of the last phase of scheduling which is represented in this report is solved by constructing as many straight runs as possible for the operator's assignment.

It is difficult to conclude exactly about the reductions in mileage of trip, staff, and overall cost by using the electronic computers, until this new method is put to work. However, the author feels that a reduction of about 5% in the service mileage and about 50% or more in staff reduction might be expected. Besides this, the convenience and ease of scheduling would allow transit companies to increase the number of schedules and revisions per year and would facilitate the development of a schedule on short notice.

ACKNOWLEDGMENTS

I sincerely thank my Major Advisor, Dr. Samy E. G. Elias, for his interest and invaluable guidance during the preparation of this report and for his counsel in innumerable matters not particularly related; and to Dr. George F. Schrader for his encouragement and counsel throughout the year.

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APPENDIX

PROGRAM TO MAKE STRAIGHT RUNS FOR BUS COMUTE

```
      PRINT 1000,
 1000 FORMAT(49H  ST RUN  SCHEDULE    P/OUT    P/IN  TOTAL TIME)
    1 FORMAT(I2,I2,F4.0,F4.0,F3.0,F3.0,F3.0)
    5 FORMAT(I14,F13.0,F8.0,F13.0)
    7 FORMAT(2H**,13,19,F13.0,F8.0,F13.0)
      DIMENSION REL(50),RLF(50)
      COSTO=1.5
      COSTP=1.0
      L=0
      K=0
    6 READ1,M,I,POUT,PIN,TERM,RL1,RL2
      REL(1)=TERM
      DO 71 JL=2,50,2
   71 REL(JL)=RL1
      DO 72 JK=3,50,2
   72 REL(JK)=RL2
      RLF(1)=POUT+TERM
      DO 101 IM=2,50
      JM=IM-1
      RLF(IM)=RLF(JM)+REL(IM)
  101 CONTINUE
  102 TOTI=PIN-POUT
      IF(TOTI-783.)2,3,4
    2 PRINT5,M,POUT,PIN,TOTI
      GO TO 6
```

```
 3 TOTI=TOTI+17.
   K=K+1
   PRINT7,K,M,POUT,PIN,TOTI
   GO TO 6
 4 IF(TOTI-867.)3,3,8
 8 IF(L)10,9,11
 9 L=L+1
   ST1=POUT+800.
   DO 12J=1,50
   IF(ST1-RLF(J))14,13,12
12 CONTINUE
13 TOTI1=ST1+17.
   K=K+1
   PRINT7,K,M,POUT,ST1,TOTI1
   POUT=ST1
   TOTI=TOTI-800.
34 IF(TOTI-783.)15,16,17
15 PRINT5,M,POUT,PIN,TOTI
   GO TO 6
16 TOTI=TOTI+17.
   K=K+1
   PRINT7,K,M,POUT,PIN,TOTI
   GO TO 6
17 IF(TOTI-867.)16,16,18
18 IF(L)19,9,11
11 L=L-1
   ST2=PIN-800.
```

```
   DO 22 LM=1,50
   IF(RLF(LM)-ST2)22,23,24
22 CONTINUE
23 TOTI2=PIN-ST2+17.
   K=K+1
   PRINT7,K,M,ST2,PIN,TOTI2
   PIN=RLF(LM)
   TOTI=TOTI-800.
39 IF(TOTI-783.)25,26,27
25 PRINT5,M,POUT,PIN,TOTI
   GO TO 6
26 TOTI=TOTI+17.
   K=K+1
   PRINT7,K,M,POUT,PIN,TOTI
   GO TO 6
27 IF(TOTI-867.)26,26,28
28 IF(L)29,9,11
14 ST1=0
   ST1=RLF(J)-POUT
   IF(ST1-867.)81,81,82
81 TOTI1=ST1+17.
   TOTI=TOTI-RLF(J)+POUT
   K=K+1
   PRINT7,K,M,POUT,RLF(J),TOTI1
   POUT=RLF(J)
   GO TO 34
82 OVERT=RLF(J)-867.-POUT
```

```
      OVER=OVERT*COSTO
      PENLT=RLF(J-1)-800.-POUT
      PENL=PENLT*COSTP
      IF(PENL-OVER)86,87,87
   86 TOTI1=RLF(J-1)-POUT+17.
      K=K+1
      PRINT7,K,M,POUT,RLF(J-1),TOTI1
      TOTI=TOTI-RLF(J-1)+POUT
      POUT=RLF(J-1)
      GO TO 34
   87 TOTI1=RLF(J)-POUT+17.
      K=K+1
      PRINT7,K,M,POUT,RLF(J),TOTI1
      TOTI=TOTI-RLF(J)+POUT
      POUT=RLF(J)
      GO TO 34
   24 ST2=0.0
      ST2=PIN-RLF(LM-1)
      IF(ST2-867.)91,91,92
   91 TOTI2=ST2+17.
      TOTI=TOTI-PIN+RLF(LM-1)
      K=K+1
      PRINT7,K,M,RLF(LM-1),PIN,TOTI2
      PIN=RLF(LM-1)
      GO TO 39
   92 PENLT=RLF(LM)-PIN+800.
      PENL=PENLT*COSTP
```

```
      OVERT=RLF(LM-1)-PIN+867.
      OVER=OVERT*COSTO
      IF(OVER-PENL)36,36,37
   36 TOTI2=PIN-RLF(LM-1)+17.
      K=K+1
      PRINT7,K,M,RLF(LM-1),PIN,TOTI2
      TOTI=TOTI-PIN+RLF(LM-1)
      PIN=RLF(LM-1)
      GO TO 39
   37 TOTI2=PIN-RLF(LM)+17.
      TOTI=TOTI-PIN+RLF(LM)
      K=K+1
      PRINT7,K,M,RLF(LM),PIN,TOTI2
      PIN=RLF(LM-1)
      GO TO 39
   10 STOP
   19 STOP
   29 STOP
      END
```

AUTOMATION IN SCHEDULING FOR TRANSIT OPERATORS

by

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AN ABSTRACT OF A MASTER'S REPORT

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MASTER OF SCIENCE

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1964

The transit system has been the dominant force in shaping the nation's cities for years and will continue to do so in the future. Due to post-war economy and population growth in recent years, a declining trend in the use of public transit in favor of automobiles has created a transportation crisis. This has demanded an immediate and effective solution for the survival of existing public transit companies. Reduction in operating cost, by rescheduling, has been one of the objectives of transit companies, to maintain operations on a profitable scale. The high computing speed and accuracy of the electronic computers resulted in quick and efficient rescheduling technique by avoiding manual methods of lengthy calculations, thereby helping to overcome the problem.

The whole problem of transit scheduling may be subdivided as follows:

(1) Partitioning the city or town in zones with routes to serve these areas and determining the passenger load, and hence, the vehicle requirements (the number of buses needed per route).

(2) Establishment of headways; i.e., how often should the buses run?

(3) Run assignments for operators; i.e., the allotment of daily work.

Research has already been done on the first two phases using electronic computers. The last phase of scheduling, "Run assignment for operators," is presented in this report. FORTRAN Language is used to develop the program for scheduling operators' run assignments on the I.B.M. 1620 electronic computer.

The ideal schedule for a company would be one with all straight runs, since it costs less and is preferred by employees. However, the variations in service trip lengths and the restrictions of labor union contracts make this practically impossible.

The following procedures may be used for automation in scheduling assignments for transit operators: The transit companies schedule each route separately by constructing as many straight runs as they can on the basis of total time of work from pull-out time and pull-in time. The pieces of work are utilized in constructing split runs, and the remaining unscheduled pieces of work are added to the extra board to complete the assignment.

It is difficult to estimate exactly about the reductions in operating costs by using the electronic computers, until this new method is put to work. However, a reduction of about 5% in the service mileage and about 50% or more in the staff reduction might be expected. Besides this, the convenience and ease of scheduling would allow transit companies to increase the number of schedules and revisions per year and would facilitate the development of a schedule on short notice.