A DIGITAL COMPUTER SOLUTION TO THE TRANSIT OPERATOR ASSIGNMENT PROBLEM

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PREFACE

In recent years, the transit volume, i.e., intracity bus passenger loadings, has been steadily decreasing. The reasons are numerous, but the decline in the usage of public transit and the ever increasing number of automobiles on the road has not only posed problems for transit organizations but also, for city planners. Various solutions have been suggested to reverse this trend, but time is needed to assess the validity of such solutions. However, even those public transit companies which hold this hopeful outlook are faced with the immediate necessity of staying in business long enough to benefit from any anticipated increase in demand for their service.

Reduction in operating cost, through re-scheduling, has been the aim of such companies seeking to maintain operations on a profitable basis. Yet, the best manual methods fall short of solving the problem because computations cannot be made quickly enough to keep pace with changing conditions. As a result, attention has been directed to the high speed computer as the means to overcome these computational difficulties.

The total problem of transit scheduling is customarily subdivided into:

1. Partitioning the city or town into areas with routes

to service these areas and determining the passenger load, and thus, the vehicle requirements (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 establishment of daily work.

Previous research has been accomplished on the first two phases, using digital computer facilities. Reference to part of this research is made in Appendix C and D.

The study undertaken herein, is on the third phase of scheduling, "Run Assignments for Operators." The difficulty encountered in arranging and scheduling runs for bus operators is brought about by the many variables which go into the make-up of specifying the daily work for each man. Both operating variations in time per trip and the union contract restrictions on what constitutes a run, are the reasons for this situation.

Indebtedness is acknowledged to Professor H. G. Thuesen, Chairman of my Advisory Committee and Professor Wilson J. Bentley, Dean M. R. Lohmann, Professor William Granet, Dr. H. T. Fristoe, and Dr. P. Torgersen, members of my Advisory Committee, for their invaluable guidance and resolution in seeing this thesis through; to Professor Darrell R. Shreve for enabling me to use the facilities of the University Computing Center which include the I.B.M. 650 digital computer, and to the people of Stillwater, Oklahoma, who directly or indirectly made my stay in their town a pleasant one.

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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 the operator assignment that pays less than 8 hours.
St.R.	Straight run	A straight run is a run so constructed as to be composed of continuous hours of pay (at least 8.00 hours).
St.R.No.	Straight run number	A straight run number is a specific straight run designated by a specific number.
Sp.R.	Split run	A split run is a run so constructed to have an unpaid interval or intervals between its pieces of work (at least 8.00 hours).
Sp.R.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.
To.Ti.	Total time	The total time for which the operator is paid (could include report time, penalty time, overtime, etc.).
R.Ti.	Report time	Report time is a specific amount of time (10 minutes) which the operator receives for every St.R. and each P.W. in his assignment.
Spd.Ti.	Spread time	Spread time is the total working time plus the unpaid time of a split run.
Sch.No.	Schedule number	A schedule number is a bus that goes over a specific route at a certain time designated by a certain number.

P/o	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, or a schedule number.
Rel.pt.	Relief point	Relief point is a certain location or locations on each route where operators may be relieved or assigned to the bus.
Term.T.	Terminal time	Terminal time is the driving time between the garage and the first relief point.
Rel.1	Relief 1	Relief 1 is the time between first and second relief points.
Rel.2	Relief 2	Relief 2 is the time between second and first relief points.

CHAPTER I

INTRODUCTION

The Hypothesis

In this dissertation, the use of the I.B.M. 650 digital computer is proposed as a means of solving the transit operator assignment problem. The primary purpose in suggesting the use of the digital computer is the elimination of the necessity for the present lengthy manual calculations. This present manual method seriously curtails an amount of desirable rescheduling which is necessary to meet the ever changing service requirements.

Reduction in operating cost, through rescheduling, has been one of the objectives of transit companies seeking to maintain profitable operations. Yet such reduction in operating costs, if carried too far, may result in less effective service and additional declining revenue. Thus, transit companies require the capability for almost instantaneous rescheduling to maintain effective service. This dissertation will illustrate a method for acquiring the aforementioned capability.

Factors Currently Affecting Bus Transit Systems

It would not take much probing to discover that transit volume has been steadily decreasing since the end of World War II. The reasons are primarily a result of the post-war economy. Increased production and use of private automobiles has been one major factor. Another cause has been the steadily increasing trend to move out of cities, which has resulted in the gradual shifting of population centers from the city to the surrounding, expanding suburbs. This shift has been accompanied by the displacement of major shopping areas from the city to the suburbs, thus decreasing the necessity for resorting to the "downtown" area for consumers' needs.

The "Car Pool", an American institution which was developed to its highest degree during World War II, is now a permanent fixture in transportation, especially in commuting to the work place, and in transporting children to school. As a side effect, the car pool has allowed the housewife the use of the family car for her needs while her husband is at work.

The decline in usage of public transit and the ever increasing number of automobiles on the road has not only posed problems for transit organizations, but also for city planners, who are continually attempting to make the city the center of culture, business, and retail trade. Planners are constantly vexed as to how to provide for the flow of people in and out of the heart of the city. In the remainder of the chapter, an attempt will be made to discuss various points which show the need for modern efficient transit.

The Case for Modern Rapid Transit

One of the most powerful forces in shaping an American city is transportation. As a matter of contrast, consider the relative merits of New York City and Los Angeles. New York has one of the most complete transportation systems in the world, utilizing privately owned railroads, and city operated subways and buses. It is a world center of trade, finance, and culture, which serves as a hub for the surrounding metropolitan area. Los Angeles, on the other hand, has never developed an extensive public transit system, nor have the inhabitants indicated any desire for any form other than the automobile. As a result, streets, expressways, and parking facilities have displaced the city to the point where it is a sprawling mass.

Mechanized urban transportation, which began its development in the early 1900's, enabled the city to grow to almost any size that men could manage. Until the latter part of the 1920's, the streetcar was the major vehicle of mass transportation. Although the automobile had made its debut, the Depression and World War II delayed its impact. Apparently, city officials, city planners, and transit managements continued to believe that city transportation patterns would remain the same after World War II, as it had been for the previous half century. Automobile use was expected to rise with the increased availability; but it was presumed that people with businesses in town would continue to patronize public transportation, yet these people did not conform to this plan. The post war economic boom not only saw automobile production soar, but also people using their cars more and more for trips that were previously made via public transit. As car sales increased, transit riding decreased. The number of transit riders reached a peak in 1945 - the last year that cars were hard to get. Each year since then 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.[1] 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. These facts are graphically illustrated in Figure 1. Railroad commuter volume has decreased, and in spite of periodic fare increases, most roads' passenger operations are functioning at a monetary loss, stabilized in some instances by freight revenues.

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[1]The Editors of Fortune, The Exploding Metropolis, (New York, 1957), p. 34.

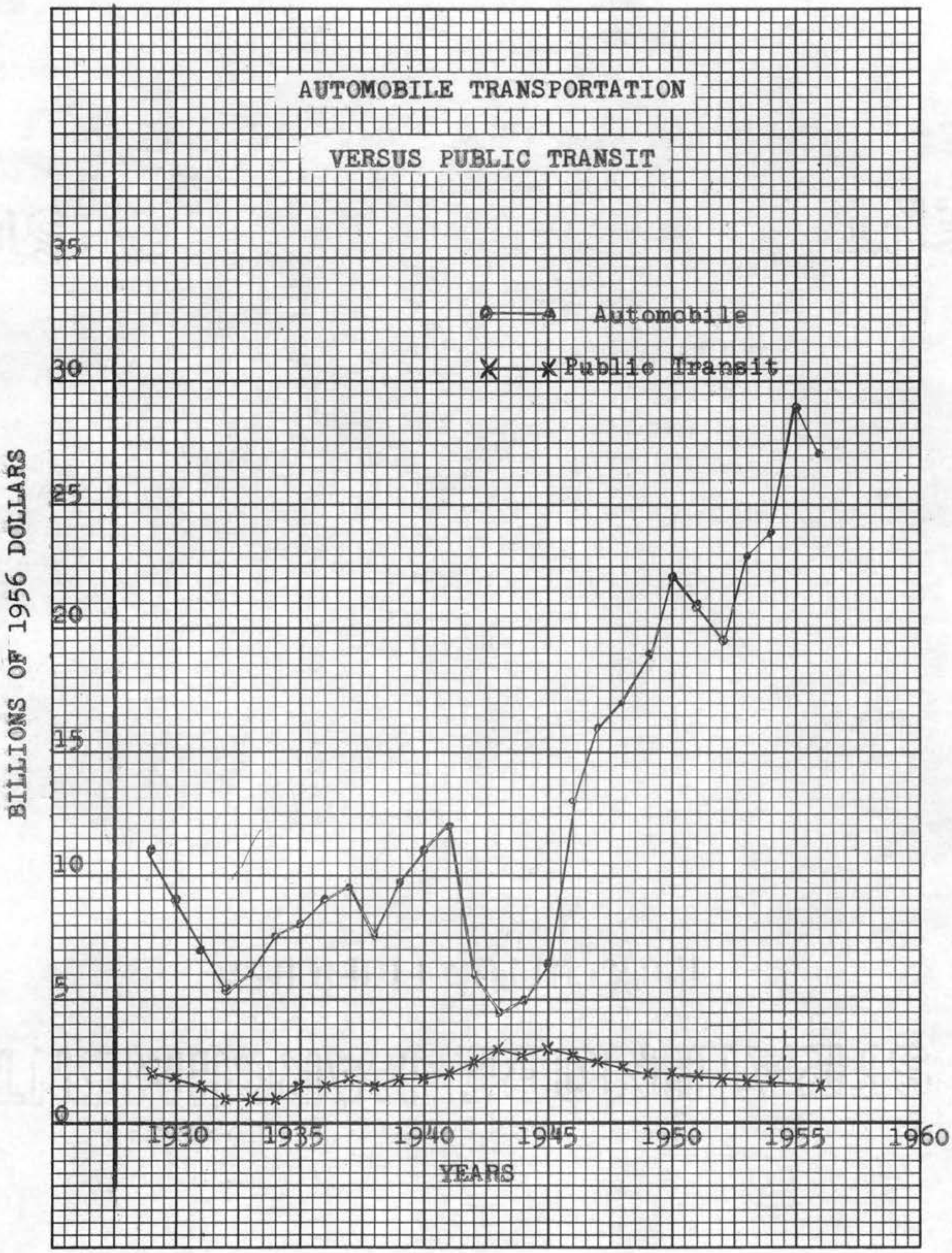

AUTOMOBILE TRANSPORTATION
VERSUS PUBLIC TRANSIT
Automobile
Public Transit
BILLIONS OF 1956 DOLLARS
35
30
25
20
15
10
5
0
1930
1935
1940
1945
1950
1955
1960
YEARS

Figure 1

Recent legislation (Federal Aid Highway Act) will provide additional funds to finance a super-highway net that will skirt or enter 90% of all cities of more than 50,000 population. The Bureau of Public Roads believes that the proposed program of expressways will relieve downtown traffic congestion. City planners, however, do not all agree. Some feel the only way to alleviate the situation is to get the people out of cars and into public transit; in other words, move bodies, not vehicles. They also feel that if some of the federal highway funds could be allocated for transit, then systems could be provided which would get people to work faster and cheaper than by car. Suitable systems would reduce traffic congestion which in itself would be a boom to Bus Transit.

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 a metropolitan area. Private transit managements cannot cope with expansion without subsidized aid. Construction of more parking facilities will require the usage of valuable property for less productive purposes. If congestion continues, it is feared that the public will resort to shopping exclusively in suburban centers, in effect, abandoning the city. The trend has already been evidenced by the opening of branches by large renowned city department stores, medical clinics, and banks. It is the belief of many planners, that unless public transit is vastly improved and patronized, the city will cease to exist as we know it today, and become instead merely a centralized headquarters area for business and industrial staffs.

CHAPTER II

DIVISION OF THE SCHEDULING PROBLEM

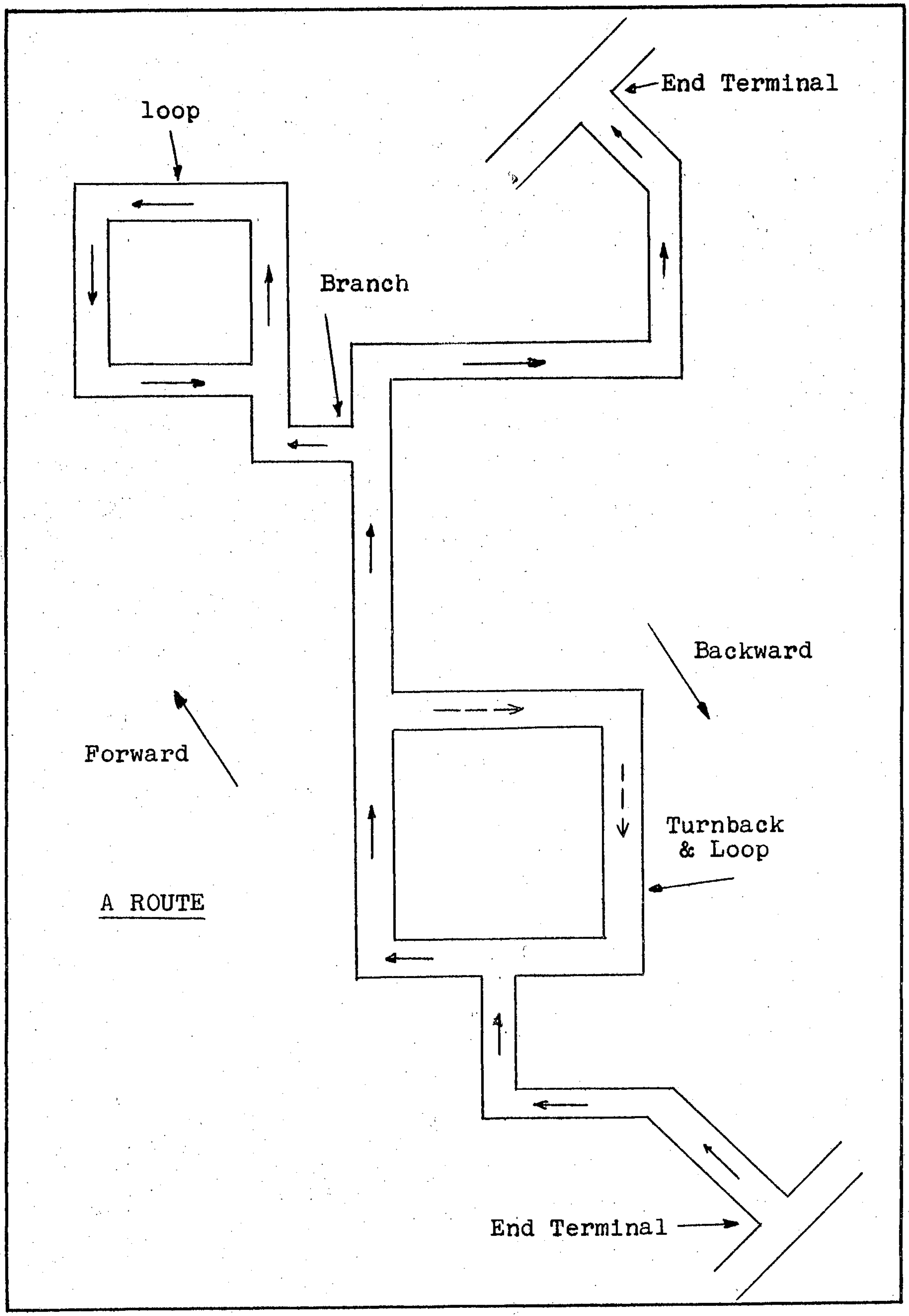
Out of a United States working force of sixty-six million, commuters make up a scant ten million. Yet, their daily cycle from home to work accounts for a larger volume of passenger traffic than any other type of weekday travel. Six million of them get to work and back by automobiles, 450,000 by train, and three and one-half million by bus, subway, or rapid transit. In many cities the bus system is the major commercial means of transportation into and within the city. In other cities the bus must compete with the train and the subway system as well as the taxi. The intercity motor bus operation is essential, forming an integral part of the passenger transportation system, linking thousands of communities.

There is a variety of reasons for adoption of buses in transit operations among which are the following: (a) flexibility in traffic, (b) individual power supply, (c) ability to pass each other, (d) through service to off-route locations, (e) ability to combine routes with one vehicle rendering the service, (f) low initial cost, and (g) curb discharge.

The city bus transit system is usually divided into routes. A route is the street or sequence of streets that a bus follows in order to move between two specified locations; usually between the downtown area and a residential or suburban area. A route may have any number of branches, turnbacks, loops, and end terminals. On each route there will usually be many schedule numbers (see Figure 5). A schedule number is a bus that goes over a specific route at a certain predetermined time.

Factors in Operations

There are operational factors in the transit industry which sometimes present problems. The transit industry is subject to traffic peaks in the morning and in the late afternoon, as well as falling-off of traffic on week ends. To meet these peak traffic demands, it is necessary to maintain equipment in excess of that which otherwise would be needed. Today bus scheduling is a big problem, in fact many transit company executives admit that bus scheduling is their biggest problem. These peak periods add to schedule difficulties. During the peak period, the schedule may call for a transit vehicle over a particular route every two or three minutes, whereas, during the off-peak period, a vehicle every ten or twelve minutes or less often may be adequate. In addition to bus allocation problems, this necessitates a certain amount of split shifts for operators,



End Terminal
loop
Branch
Backward
Forward
Turnback
& Loop
A ROUTE
End Terminal

Figure 2

who may work, for example, four hours in the morning, with three hours off, and four hours again in the afternoon. The splitting of shifts has always been a matter of contention between transit management and transit employees with the latter contending that there should be extra compensation for the time between shifts.

A factor in transit operations increasingly being used is that of the express run, which has fewer stops and thereby appreciably cuts down on running time. It is estimated that the time for boarding and alighting is about thirteen per cent of scheduled running time,[1] so the elimination of stops can speed up the run. The elimination of a number of stops reduces operational expense. The many stops in urban operations cause a large amount of maintenance of equipment and makes for a much higher consumption of gasoline and oil than is found in intercity passenger operations. But on the other hand, income from such an express run is often low.[2]

One of the advantages already mentioned in bus city operations is the flexibility of the motor bus. However, its flexibility often makes for many requests for additional routing or rerouting and thus rescheduling. The great postwar exodus to suburbia has scattered commuters through the

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[1]Charles A. Taff, Ph.D, Commercial Motor Transportation (Illinois, 1955), p. 638.

[2]Ibid.

United States countryside surrounding cities. When the bus serves outlying areas, residents frequently contact their local city officials to petition that the bus route come down their street. The traffic potential in outlying areas is limited, but it is difficult to convince residents of that fact. But at the same time city transit firms realize that if scheduling could be set up in a really efficient manner, it would offer one of the greatest possibilities for profitable transit operation. The whole problem of scheduling is customarily divided into:

(1) Partitioning the city or town into areas with routes to service these areas and determining the passenger load, and thus, the vehicle requirements (number of buses needed per route).

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

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

Determination of Passenger Load And Vehicle Requirements

Information to develop service requirements for a route must first be recorded by trained traffic checkers. These traffic readings are passenger counts taken as vehicles pass strategic points along the line, such as the heaviest hauling points, turnback locations, branching and transfer points. The men work in shifts around the clock, until all routes are observed. This provides the basic schedule figures needed to regulate the operations. In this manner the entire system is re-checked for complete schedule revision for the fall, spring, and summer traffic conditions.

Without traffic readings, schedules could not be built efficiently nor could it be maintained in order to give the best necessary service with the least amount of equipment and man power.

In assigning checkers,[3] according to the preplanned arrangement to completely cover a route survey of passenger loading, some specific recordings are necessary to properly summarize the data collected. These are as follows:

a. Line being read

b. Location of reading point

c. Direction of reading

d. Date of reading

e. Type of reading - arriving or leaving

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[3]J. T. Harman, Scheduling Mass Transportation Vehicles Electronically, (February 20, 1958), A Speech to the American Marketing Association: "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.

f. Weather conditions

g. Time of vehicle

h. Number of passengers on each vehicle.

The field checks obtained supply source information for applying loading standards for regulating service. When a load factor - the total number of seats plus standing spaces per vehicle - is divided into the number of bus passengers on a particular route per hour, the result is the number of buses required per hour per route.

As an example in this discussion, it could be assumed that a specific route would require 75 buses during the morning rush periods; 25 in midday; 70 through the afternoon rush period, with 10 vehicles operating in the night service. This variation in the number of vehicles required during these periods creates a very uneconomical use of equipment.

Establishment of Headways

Headways is the time, in minutes, between vehicles. This, in turn, determines the spacing of 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 necessary to travel between two points on a route. It is the most important time of a schedule as far as operations are concerned. No schedule could operate effectively or without loss of man power unless it had the proper running time. If a line does not have enough running time, all trips might be late, and it would cause some trips to be cut. If a line has too much running time, there would also be a poor operation, for it would be necessary for all vehicles to drag along, "killing time", or else run ahead of schedule and cause uneven spaces in the headway. When an operator runs ahead of schedule, he causes the next operator to be late and haul more passengers than he ordinarily would. This makes the second operator do more than his normal amount of work. Running time should be determined in order that an operator can haul his passengers safely and provide them with the service to which they are entitled.

Running time is compiled through time studies made under actual operating conditions. The resulting figures are applied to new schedules so that the proper time is allocated to each series of trips, providing maximum operating speed with safety.

As arranged, running time varies each hour on a line of 90 minutes in one-way time; a schedule could have up to six intermediate time points. Such points are mainly assigned to check adherence to schedule. They are spaced approximately equal distances apart, along the route.

The daily total and accumulated miles operated per vehicle provide the maintenance department with service controls, while man-hours as scheduled become the basis for payroll accounting.

The man-hours scheduled are then broken down into work assignments for each operator; the results being called runs.

Run Assignments for Operators

The difficulty encountered in arranging runs for bus operators is brought about by the many variables which go into the make-up of specifying daily work for each man. Both operating variations in time per trip and the union contract restrictions on what constitutes a run, are the reasons for this situation.

Specifically, difficulties in arranging runs are brought about by the variation in trip lengths. Trips are combined or broken into segments of time in the process of constructing runs.

The labor contract often states that all assigned regular runs must pay a specified number of hours (normally eight hours). The fringes in addition to the operating hours are items such as the following:

- Unworked time added to a run to make an eight-hour day
- Preparation and storage time
- Distance relief and travel time
- Waiting time
- Spread penalty for constructing a run beyond a certain number of hours (12:25 hour)

Overtime after a basic eight-hour day (at time and a half)

Percentage of straight and split runs

Minimum length of a piece of work.

The foregoing explains the difficulty encountered in manual scheduling methods. Rescheduling has been a principal avenue open to transit companies seeking to maintain operations on a profitable basis, especially so in these days when they are confronted with the double-barreled competition of the private automobile and the ever-increasing traffic congestion.

Reduction in operating costs can play an important role, but such reduction if pushed too far; will result in less effective service and another decline in revenue.

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

CHAPTER III

PRESENT SCHEDULING METHOD OF "A" COMPANY

In the following chapter the present scheduling method of "A" company will be introduced.

When "A" company moves into a city to operate a bus transit system, it does so either by taking over from another existing firm or starting as a new concern. In either case, the decision as to which routes the company will operate is finally based upon an agreement between the company and the city commissioners. Changes, in the form of additions or deletions of existing routes, are sometimes undertaken to keep abreast of the city's ever changing needs. A decision is reached after studying present and potential need of the city residents, and the economics of servicing this need.

The first step that the company will take in establishing and/or changing routes is to go into areas that they intend to serve, estimate the number of residents, and then they estimate the number of residents that use public transportation. The latter estimate is based upon several factors, such as the geographic location, the type of residence, the kind of work, the nearby industries, etc. The ultimate estimate is based upon experience rather than any formal or analytical techniques. Dividing the number of expected passengers by a load factor, which depending on the capacity of the buses, results in the number of buses needed in this special area or for this special route. Ordinarily, in the early hours of the day and late afternoon, there is a rush period during which passengers are going to or coming from work, hence requiring a greater number of buses. Generally, a rush period requires three times as many buses as are needed during normal service periods.

The next step is the determination of the round trip mileage for each route. Dividing this mileage by the average speed of the bus, which is usually about 12 m.p.h., will give the time for a round trip. The headway, which is the time interval between two vehicles on a specific route, is found either by dividing the round trip time by the number of buses or by some related assumption. The headway during the rush periods, is always less than at normal service periods (one-half to one-third the normal headway).

As an example, if some passengers wish to be downtown for work at 7:00 a.m., then the first bus might arrive there at 6:50 (6:50 indicates 6 hours and 50 minutes, 6.50 indicates 6 hours and 50/100 of an hour). If the headway is 15 minutes then the second bus would be there at 7:05, and so on. If eight buses are needed to carry passengers downtown during the morning rush period, the arrival times are listed on a sheet of paper, and then calculated to determine the pull-out times from the garage. To further clarify this, the following example is given. Assume that on a certain route these data apply:

(1) Early rush period is until 9:00 a.m.

(2) Round trip time is one hour

(3) The desired headway is 10 minutes, then

(4) Six buses are needed downtown between the hour of 8:00 a.m. and 9:00 a.m.

On a sheet of paper the timing points on this route are indicated. Scheduling is simplified by including two round trips on one sheet. So if on route "B" the timing points are Main Street, X_1, X_2, and X_3, then this is indicated on a sheet of paper as follows:

Pull out	Main St.	X_1	X_2	X_3	Main St.	X_1	X_2	X_3	Main St.

and the six buses will be shown as follows:

Pull out	Main St.	X_1	X_2	X_3	Main St.	X_1	X_2	X_3	Main St.
									800
									810
									820
									830
									840
									850

Notice the difference in time is the ten (10) - minutes headway.

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

Sch. No.	Pull Out	Main St.	X_1	X_2	X_3	Main St.	X_1	X_2	X_3	Main St.
1	555	600	615	630	645	700	715	730	745	800
2	605	610	625	640	655	710	725	740	755	810
3	615	620	635	650	705	720	735	750	805	820
4	625	630	645	700	715	730	745	800	815	830
5	635	640	655	710	725	740	755	810	825	840
6	645	650	705	720	735	750	805	820	835	850

750 - 650 = 1 hour

850 - 750 = 1 hour

Notice the time for a round trip is one hour.

Each one of these buses will be given a number called the schedule number as shown above.

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

Applying this to the above example with previous assumptions of:

(1) Early rush period is until 9:00 a.m.

(2) Round trip time is one hour

(3) The desired rush headway is ten minutes, then

(4) Six buses are needed downtown between the hour of 8:00 a.m. and 9:00 a.m.

Plus the following assumptions:

(5) The desired normal headway is twenty minutes, then

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

Sch. No.	Pull Out	Main St.	X_1	X_2	X_3	Main St.	X_1	X_2	X_3	Main St.	Pull In
1	555	600	615	630	645	700	715	730	745	800	
2	605	610	625	640	655	710	725	740	755	810-	815
3	615	620	635	650	705	720	735	750	805	820	
4	625	630	645	700	715	730	745	800	815	830-	835
5	635	640	655	710	725	740	755	810	825	840	
6	645	650	705	720	735	750	805	820	835	850-	855
1		800	815	830	845	900	915	930	945	1000	
3		820	835	850	905	920	935	950	1005	1020	
5		840	855	910	925	940	955	1010	1025	1040	

This will go on until the second rush period, when more buses will have to be inserted in the schedule with the proper headway time. After this period is over, service returns to normal. This route is customarily rescheduled again for Saturdays and Sundays.

Following are actual weekday, Saturday and Sunday schedules on route No. 13 of "A" company; from which is found that:

(1) Round trip time is between 1:07 and 1:15 hours

(2) Headway at rush period is 12 minutes and at normal service is 35 minutes

(3) Five buses were needed downtown (4th and Main) between the hour of 8:00 and 9:00.

SCH. NO.	PULL OUT	4TH MAIN	28CT 30ST	21ST YALE	21ST UTICA	4TH MAIN	28CT 30ST	21ST YALE	21ST UTICA	4TH MAIN	28CT 30ST	21ST YALE	21ST UTICA	4TH MAIN	PULL IN
282	540	---	---	---	---	545	615	627	636	652	730	742	752	807	
283	552	---	---	---	---	557	627	639	649	704	742	754	804	819	824
284	604	---	---	---	---	609	639	651	701	716	754	806	816	831	836
281	511	516	546	556	606	621	651	703	713	728	806	818	828	843	
285	628	---	---	---	---	633	703	715	725	740	818	830	840	855	900
286	640	---	---	---	---	645	715	727	737	752	---	---	---	---	ChX206
282		807	845	855	905	920	955	1005	1015	1030	1105	1115	1125	1140	
281		843	920	930	940	955	1030	1040	1050	1105	1140	1150	1200	1215	
282		1140	1215	1225	1235	1250	125	135	145	200	235	245	255	310	
281		1215	1250	100	110	125	200	210	220	235	310	320	330	345	
282		310	348	400	410	425	503	515	525	540	618	630	640	655	
288	FrX1355	--	---	---	---	437	515	527	537	552	630	642	652	707	712
289	FrC263	--	---	---	---	452	529	541	551	606	---	---	---	---	611
281		345	425	437	450	505	543	555	605	620	658	710	720	735	
290	FrX353	--	---	---	---	517	555	607	617	632	---	---	---	---	637
287	FrX352	415	452	504	514	529	607	619	629	644	---	---	---	---	649
282		655	735	745	755	810	845	855	905	920	955	1005	1015	1030	
281		735	810	820	830	845	920	930	940	955	---	---	---	---	1000
282		1030	1100	1108	1115	1130	---	---	---	---	---	---	---	---	1135

ROUTE NO. 13 - WEEKDAY EAST 21ST STREET EFFECTIVE . . .

SCH NO.	PULL OUT	4TH MAIN	28CT 30ST	21ST YALE	4TH MAIN	28TH 30ST	21ST YALE	4TH MAIN	28CT 30ST	21ST YALE	4TH MAIN	PULL IN
282	610	---	---	---	615	645	655	720	755	805	830	
281	535	540	610	620	645	720	730	755	830	840	905	
282		830	905	915	940	1015	1025	1050	1125	1135	1200	
281		905	940	950	1015	1050	1100	1125	1200	1210	1235	
282		1200	1235	1245	110	145	155	220	255	305	330	
281		1235	110	120	145	220	230	255	330	340	405	
282		330	405	415	440	515	525	550	625	635	700	
281		405	440	450	515	550	600	625	700	710	735	
282		700	735	745	810	845	855	920	955	1005	1030	
281		735	810	820	845	920	930	955	---	---	---	1000
282		1030	1105	1115	1140	---	---	---	---	---	---	1145

ROUTE NO. 13 - SATURDAY EAST 21ST STREET EFFECTIVE. . .

SCH NO.	PULL OUT	4TH MAIN	28CT 30ST	21ST YALE	4TH MAIN	28CT 30ST	21ST YALE	4TH MAIN	28CT 30ST	21ST YALE	4TH MAIN	PULL IN
281	625	630	700	707	730	800	807	830	900	907	930	
281		930	1000	1007	1030	1100	1107	1130	1200	1207	1230	
281		1230	100	107	130	200	207	230	300	307	330	
281		330	400	407	430	500	507	530	600	607	630	
281		630	700	707	730	800	807	830	900	907	930	
281		930	1000	1007	1030	1100	1107	1130	---	---	---	1135

ROUTE NO. 13 - SUNDAYS & HOLIDAYS EAST 21ST STREET EFFECTIVE. . .

The last step in completing the schedule, and that which is probably the most difficult is determining the runs, i.e., the individual operator assignment to a specific bus. This step is partially restricted by the labor contract. The labor contract that "A" company has with its union requires the following: (See Appendix B for a labor management contract on scheduling restrictions.)

All runs pay at least 8 hours.

Of all runs, at least 35% must be straight runs and at most 65% split runs.

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

All overtime work is paid at time and a half (i.e., 1.5 regular pay).

Split runs may have a spread time of 12 hours and 25 minutes, and 10% of these runs may have a spread of 13 hours and 25 minutes.

If the spread time is above that previously stated, then the company pays one-half the excess time as penalty.

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 report time of ten minutes).

The ideal schedule for a company would be one with all straight runs. However, the variation in service trip lengths makes this a practical impossibility. A straight run in general costs the company less and is preferred by the employee. Due to the inconvenience in relieving a driver at night if he is on a split run, it is preferred that all split runs be scheduled in the daytime.

As a general rule, transit companies schedule each route independently. This is accomplished as follows:

(1) From the schedule (time table or the "board" as it is customarily called), the scheduling department finds the total time each bus (schedule number) is in service, and the time it pulls-out and pulls-in to the garage.

(2) These service times, depending on their length, are divided into eight hours of work.

(3) Although step 2 is done on a trial and error basis, there are two rules which may be used as guides. These are:

a. Pieces of work will be easier to schedule into runs if they are of about four hours duration.

b. Each route should be balanced separately (i.e., number of A.M. pieces of work equals number of P.M. pieces).

(4) After the board has been broken into eight hour straight runs, and pieces of work, the A.M. pieces of work are listed on one side of a sheet of paper and the P.M. on the other side in the order of occurrence. Split runs are constructed by combining A.M. with P.M. pieces of work.

While this will take care of most of the pieces of work, not all these pieces will fit well together into split runs; thus, leaving some pieces still unscheduled.

(5) At this point, the percentage of straight runs to split runs is checked. If the number of straight runs is over the minimum specified by the labor contract (and usually is), then some of the straight runs will be broken down to reconstruct, with unscheduled pieces of work, split runs. A straight run is broken only if two split runs would result.

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

On the following page an actual run assignment is developed from breaking down Route No. 13.

	RUN NO.	SCH.NO.	TIME ON	TIME OFF	WORK	REPORT	PENALTY	STRAIT	OVER	TOTAL
	1301	281	511A P/out	125P Reld	814	10		824		824
St.R.	1351	281	125P Rel	1000P P/in	835	10		845		845
	1352	282	310P Rel	1135P P/in	825	10		835		835
	1302C	282	540A P/out	1030P Reld	450					
	1303X	283	552A P/out	824A P/in	232					
	1304X	284	604A P/out	836A P/in	232					
	1305X	285	628A P/out	900A P/in	232					
P.W.	1306X	286	640A P/out	752A Chng	112					
	1307C	282	1030A Rel	310P Reld	440					
	1353X	287	415P Chng	649P P/in	234					
	1354X	288	437P Chng	712P P/in	235					
	1355C	289	452P Chng	611P P/in	119					
	1356X	290	517P Chng	637P P/in	120					

ROUTE NO. 13-Week Day Break-Up EFFECTIVE. . .

CHAPTER IV

COMPUTER SCHEDULING OF TRANSIT OPERATORS' ASSIGNMENT

High-speed digital computers are today helping many small businesses cut operating expenses and handle an increased volume of work. These computers are still so costly that only very large corporations can afford to buy or lease them. But the small businessman can turn to computer service organizations that sell the time of large computers on an hourly basis. The businessman pays only for the time it takes to solve his particular problem. Because a high-speed computer can perform millions of calculations in an hour (from 600-4000 operations per second),[1] a wide range of problems can be economically solved in a relatively short time and by more efficient means than hand calculation.

Types of Problems

Some typical engineering problems that can best be solved by computers include stress analysis, heat and pressure calculations, vibration analysis, and engine design.

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[1]Francis Bello, "The War of the Computers," Fortune, October, 1955, p. 130.

Digital computers make possible the rapid processing of great amounts of clerical data. They cut down the time and costs spent on functions such as payroll processing, billing, shop-order writing, sales analysis and a large variety of scheduling problems.

Illustrative of these problems is that of a business which operates a fleet of trucks. The manager wanted to find out the most economical routes for them to follow. The factors that had to be considered included among other mileages, traffic congestion, toll roads, and load capacities. In just a few hours a computer analyzed ten million possible route combinations and found the best ones. Without a computer, it was estimated that it would have taken twenty years to solve the above problem. Obviously, during that time the trucker would not have been able to save several thousand dollars per year as he is now doing.[2]

A problem must be carefully studied in order to determine if it is complex and difficult enough to warrant a computer solution, and still be economical.

The problem of scheduling bus operators is certainly one which lends itself to computer techniques. The problem arises mainly from the restrictions which both the labor

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[2] I. J. Seligsohn, Using Computer Services in Small Business, Management Aids for Small Manufacturers, November, 1959, p. 3.

union's contract and the City Commissioner's regulations place on the operating companies. The wage rate of bus drivers averages $2.00 per hour while the variable cost of operating a bus approximates $0.050 per mile or $0.65 per hour (13 m.p.h.). This ratio of driver to bus cost of about three to one emphasizes the desirability of efficient scheduling.

The program described in this chapter is designed to be processed on the I.B.M. 650. It gives the scheduler a method which practically eliminates clerical work and endless hours of calculation. In the following pages, the reader will find a description of the program with instructions for its use. In general, the program is developed to follow the old manual pattern of scheduling very closely in most respects, doing exactly the same work that people did with pencil and paper, but telescoping weeks of work into a few hours. By a process of simulation, the computer internally traces the motions of a bus. 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 information supplied. A range of limits such as maximum and minimum hours of work, overtime rates, and points on the route where decision must be made, are established in advance.

The Program

The specific objective of this I.B.M. program is to construct a schedule with as many straight runs as possible and with a minimum number of unscheduled pieces of work. As mentioned previously, pieces of work not scheduled in split runs are undesirable and costly to maintain. To reach this objective, the author has found it more convenient to divide the problem into four sections, due to limitation of storage area on the computer and the complexity of the problem. The process has been arranged so that the output from one section is the input for the succeeding one.

Section I

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

B. An intermediate step is necessary to change the format by which pieces of work are punched out (Section I - A) to the appropriate form needed as input data for Section II.

Section II

Split runs are constructed by combining pieces of work.

Section III

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

Section IV

Find the total cost of a schedule.

The following special devices on the I.B.M. 650 are required:

Sixty words IAS (Immediate Access Storage)

Three index registers (A, B, and C)

Floating decimal device

I.B.M. 533 read-punch unit and proper control panels

This program does not require any special control panel wiring since the various sections of the program are developed, using either the "SOAP II" or the "FOR TRANSIT" method of programing.

In the pages that follow, the reader will find a description of each section in the program in the following order:

1. Presentation
    a. Assumptions
    b. Flow diagram
    c. Discussion
2. Preparation of data
3. Starting the program
4. Example and remarks

(Appendix A contains a complete listing of the program.)

Section I

A. 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

In this section the following assumptions are included in the body of the program:

(1) (a) A straight run should pay at least eight hours.

(b) The operator gets ten minutes for report time at the end of each run.

(c) Thus, a straight run can be composed as follows:

7:50	work time		7.83	work time
0:10	report time	or	0.17	report time
8:00	Total		8.00	Total

(2) (a) Overtime premium is at one and one-half times the regular rate.

(b) Overtime is for work in excess of eight hours and fifty minutes.

8:40	work time		8.67	work time
0:10	report time	or	0.17	report time
8:50	Total		8.84	Total

(3) The driving time between the garage and the first relief point is known, and so is the time between the first and the second relief points and backwards

between the second and the first relief points.

All of these assumptions are introduced at the end of the program in the form of "words" (See Appendix A, Section I - A). This makes it very simple to change to fit any special case without any damaging effect to the body of the program.

b. Flow diagram

(See Figure 3, page 38.)

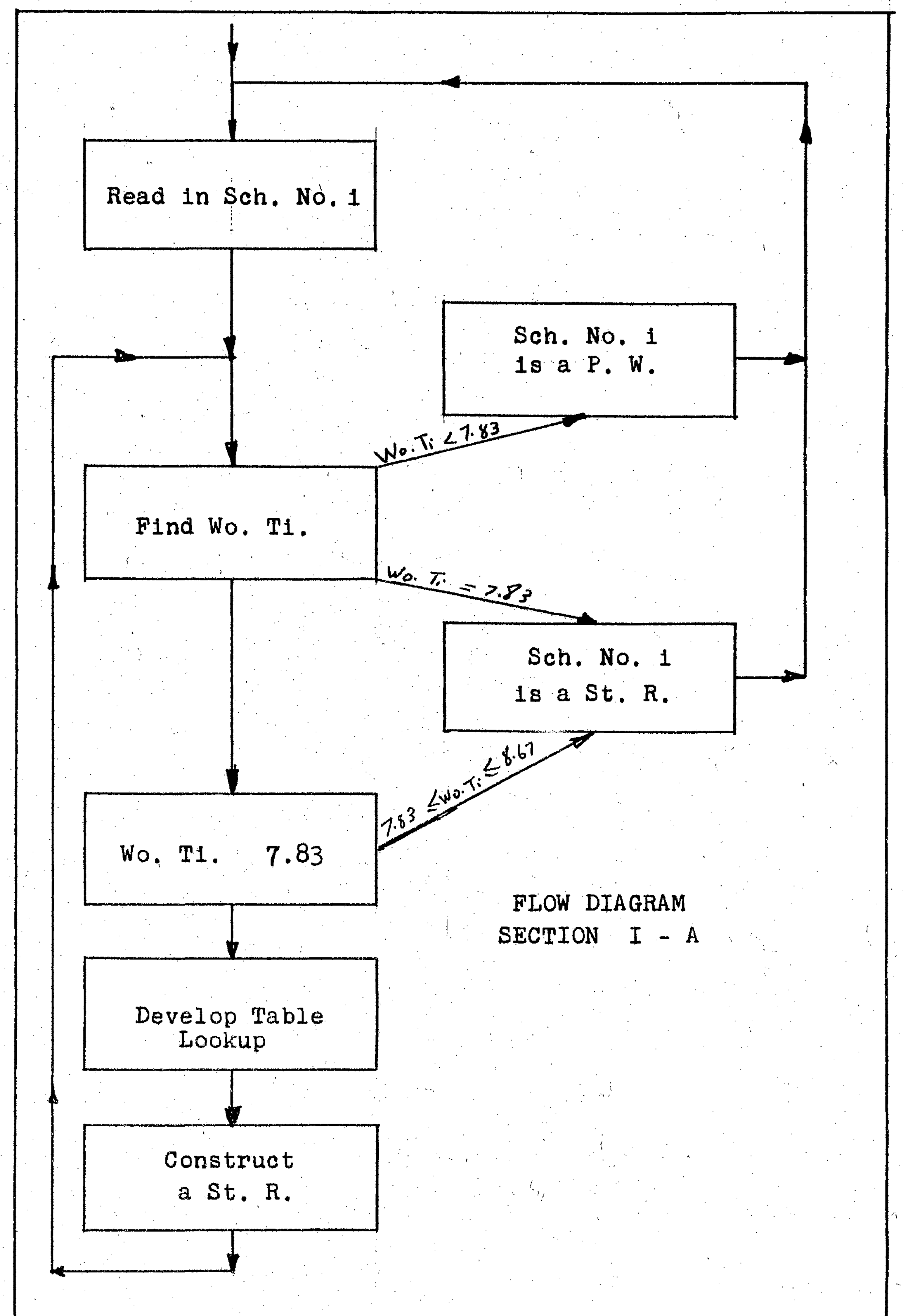

Read in Sch. No. i
Sch. No. i is a P. W.
Wo. Ti < 7.83
Find Wo. Ti.
Wo. Ti = 7.83
Sch. No. i is a St. R.
7.83 ≤ Wo. Ti ≤ 8.67
Wo. Ti. 7.83
FLOW DIAGRAM
SECTION I - A
Develop Table Lookup
Construct a St. R.

Figure 3

c. Discussion

The program is developed using the "SOAP II" method. It is designed so that the machine will do the following:

(1) The machine will accept one card (schedule number) at a time. Find the total time of this schedule number and compare it with 7.83 hours (the minimum working time for a straight run.)

(2) If the total time is less than 7.83 hours, this means that no straight runs can be developed from this schedule number, thus, the machine will print the information about this schedule number in the form of a piece of work.

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

(4) If the total time is more than 7.83 hours, the machine will do a further check 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 working overtime, thus, the machine will add 0.17 hour for report time and print the information about this schedule number as a straight run.

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

(a) Develop a table for all the relief points for this schedule number on this route.

(b) Look up the relief point which will break the total time of this schedule number to exactly eight hours or the nearest relief point larger than eight hours to construct a straight run.

(c) Check the following:

1 - See if the straight run is exactly eight hours.

2 - If there is overtime, finds its value.

3 - Look up the relief point which is ahead of the one chosen previously (i.e., that 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 run, will oscillate. If the first straight run is developed at the beginning of the schedule number, the second will develop from the end. This is desirable to avoid being left with all pieces of work either A.M. or P.M. pieces, which would create great difficulty in scheduling.

(7) At that point, the machine will pick up the working time which has not been scheduled in the straight run, and run it through all the previous steps.

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

2. Preparation of Data

Although the data to be processed may be in a form other than standard 8-10, such a handicap can be overcome by board-wiring. If the standard 8-10 board is to be used, then data cards will be in this form:

a. Columns 1 through 20 are provided for the identification of the schedule number.

b. Columns 21 through 30 are provided for identification of the pull-out time of the schedule number.

c. Columns 31 through 40 are provided for identification of the pull-in time of the schedule number.

d. Columns 41 through 80 are not used.

3. Starting the Program

The "SOAP II" method has been used in developing this section, therefore, the steps to follow on the machine are those of any "SOAP" program and can be summarized as follows:

a. 533 Read-Punch Unit

(1) Insert "SOAP II" control panel

(2) Ready read feed with assembly deck

Order of assembly deck:

(a) "SOAP II" deck

(b) Deck to be assembled (the program)

(3) Ready punch feed with blanks

b. 650 Console

(1) Set program switch to STOP

(2) Set half cycle switch to RUN

(3) Set control switch to RUN

(4) Set display switch to DISTRIBUTOR

(5) Set overflow switch to SENSE

(6) Set error switch to STOP

(7) Set (70 1951 9999) in storage entry switches

c. Press computer - reset key

d. Press program - start key

e. When read hopper empties, press end of file key. The "SOAP II" is loaded and the program is translated to the machine language and punched out.

f. 533 Read-Punch Unit

(1) Insert the 8-10 control panel

(2) Ready read feed with:

(a) The program in machine language

(b) A transfer card

(c) The data cards

(3) Ready punch feed with blanks

g. Repeat steps b through d (For additional information, see I.B.M., "SOAP II" manual, Form 32-7646-2.) The output will be a card for every straight run and one for every piece of work.

4. Example and Remarks

Example:

Input data

Sch.No.	P/o	P/in
1	590	1370
2	610	1010
3	630	1497
4	650	1490
5	670	1870
6	690	1890
7	500	2300
8	520	2320
11	590	1010
12	610	2230
13	630	1050
14	650	2270
15	670	1090
16	1390	1810
17	1430	1850
18	1470	1890

Output data

St.R.No.	Sch.No.	P/o	P/in	To.Ti.
	1	590	1370	780
	2	610	1010	400
1	3	630	1497	884
2	4	650	1490	857
3	5	670	1480	827
	5	1480	1870	390
4	6	1100	1890	807
	6	690	1100	410
5	7	500	1310	827
6	7	1445	2300	872
	7	1310	1445	135
7	8	520	1330	827
8	8	1465	2320	872
	8	1330	1465	135
	11	590	1010	420
9	12	610	1420	827
10	12	1420	2230	827
	13	630	1050	420
11	14	1485	2270	802
12	14	650	1485	852
	15	670	1090	420
	16	1390	1810	420
	17	1430	1850	420
	18	1470	1890	420

Remarks:

a. In certain cases human judgment is needed, where machine capacity is limited. The total time for schedule number "I" is 7.80 hours. If 0.17 hour for report time is added, the total time would have been 7.97 hours. The scheduler might find it more feasible to construct, from the above schedule, a straight run by paying 0.03 hour in penalty time rather than treating the schedule number as a piece of work.

b. The reader will notice that the "0.17 hour report time" is added to the working time of each straight run to give the total time.

c. The reader will notice how the machine, in constructing a straight run, did so on an oscillating basis. If a run is constructed at the beginning of the schedule number (as schedule No. 5), the second is constructed from the end (as schedule No. 6). This procedure will prevent having all pieces of work being concentrated either early in the morning or late at night.

d. The reader will notice, that for both schedule numbers, 7 and 8, two straight runs and a piece of work are constructed.

Section I

B. An intermediate step is necessary to change the format by which pieces of work are punched out (Section I - A) to the appropriate form needed as input data for Section II.

1. Presentation

   a. Assumptions - None

   b. Flow diagram - None

   c. Discussion

   The program is developed using the "SOAP II" method. It is designed to reduce the storage area needed for each piece of work from four words to two words. Instead of using one card for each piece of work, it will use one card for four pieces of work.

2. Preparation of Data

   Since all the input data for this section are the output from Section I - A, no further preparation is needed. However, one 8-10 standard card is necessary to show the number of cards to be processed.

   a. Columns 1 through 20 are provided to show the number of cards.

   b. Columns 21 through 80 are not used.

3. Starting the Program

   Same as Section I - A, (see page 42).

4. Example and Remarks

Example:

Input data

No. of cards

Sch.No.	P/o	P/in	To.Ti.
50	900	1500	600
51	500	1100	600
52	500	1700	200
53	550	1850	300
54	1600	1900	300
55	1550	1800	250
56	1550	1700	150
57	1600	1850	250
58	1625	1900	275
59	1650	1875	225
60	1650	1825	175

Output data

Word 1	Word 2	Word 3	Word 4	Word 5	Word 6	Word 7	Word 8
8000530550	0018500300	0000520500	0017000200	0000510500	0011000600	0000500900	0015000600
8000571600	0018500250	0000561550	0017000150	0000551550	0018000250	0000541600	0019000300
6000601650	0018250175	0000591650	0018750225	0000581625	0019000275		

(See remarks for further explanation.)

Remarks:

The following is a description of the output card.

a. Each card having 80 columns could have up to eight words (four pieces of work).

b. Columns 1 and 2 in each word are not used except in the first word; column 1 is used to show the number of words on the card.

c. Columns 3 through 6 in word one, three, five, and seven are used to identify the schedule number.

d. Columns 7 through 10 in word one, three, five, and seven are used to identify the pull-out time.

e. Columns 3 through 6 in word two, four, six, and eight are used to identify the pull-in time.

f. Columns 7 through 10 in word two, four, six, and eight are used to identify the total time.

Section II

Split runs are developed by combining pieces of work.

1. Presentation

a. Assumptions

In this section the following assumptions are made and included in the body of the program.

(1) (a) A split run is composed of two pieces of work and pay at least 8.00 hours.

(b) The operator gets ten minutes for report time for every piece of work.

(c) Thus, a split run can be composed as follows:

7:40	work time		7.66	work time
0:20	report time	or	0.34	report time
8:00	Total		8.00	Total

(2) (a) Overtime premium is at one and one-half the regular rate.

(b) Overtime is for work in excess of nine hours.

8:40	work time		8.66	work time
0:20	report time	or	0.34	report time
9:00	Total		9.00	Total

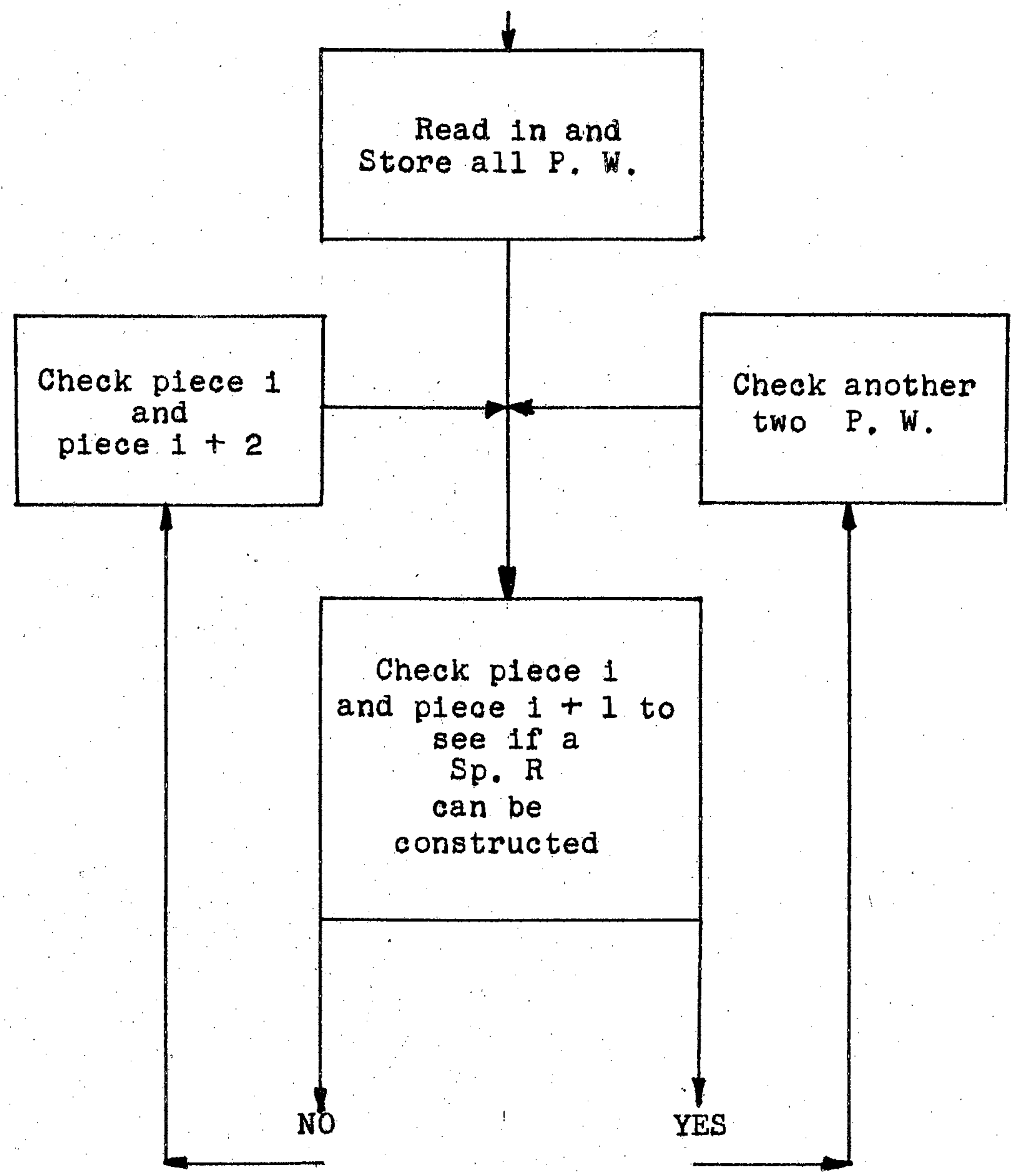
(3) Maximum spread time for a split run is:

12:25 hours or 12.42 hours

All these assumptions are introduced at the end of the program in the form of "words" (See Appendix A, Section II). This makes it very simple to change, to fit any special case without any damage to the body to the program.

b. Flow diagram

(See Figure 4, page 51.)



FLOW DIAGRAM
SECTION II

Figure 4

c. Discussion

The program is developed using the "SOAP II" method. It is designed so that the machine will do the following:

(1) The program will cause the machine to store all pieces of work on the drum.

(2) Take one piece of work at a time and check it against the others, to find the proper one with which a split run can be constructed. The checks that the machine make:

(a) That the pull-out time of the first piece of work is earlier than the pull-out time of the second. (If not reverse the order of the pieces of work and carry on with the rest of the checks.)

(b) That the pull-in time of the first piece of work is earlier than the pull-out time of the second piece.

(c) That the spread time of the two pieces of work is within the maximum limits.

Spd. Ti. - 12:25 hours

(d) That the working time of the two pieces of work is within the two limits.

$$7.66 \text{ h} < \text{Wo.Ti.}_1 + \text{Wo.Ti.}_2 < 8.66 \text{ h}$$

(3) The two pieces of work which have been found to construct a split run will be punched out under the same split run number (see example).

(4) Split run numbers begin with "1001", in order to differentiate them from straight run numbers which begin with "1".

(5) Repeat the previous steps for other pieces of work.

2. Preparation of Data

Since all the input data for this section are the output data from Section I - B, no further preparation is required. However, the last card in the program (See Appendix A, Section II) should be changed depending on the number of pieces of work being stored on the drum. A regular "SOAP" card is needed.

a. Columns 43 through 46 should have the letters "NUMB".

b. Columns 49, 50, 52, 53, 54, and 55 should have a zero.

c. Columns 58 through 61 should have a number equal to twice the number of pieces of work to be stored.

3. Starting the Program

Same as Section I - A, (see page 42).

4. Example and Remarks

Example:

Input data

8000020610	10100400	51480	18700390	60690	11000410	71310	14450135
8000081330	14650135	130630	10500420	150670	10900420	161390	18100420
4000171430	18500420	181470	18900420				

(For further clarification see Section I - B, Remarks page 48.)

Output data

Sp.R.No.	Sch.No.	P/o	P/in	Working Time	To.Ti.
1001	2	610	1010	400	854
1001	16	1390	1810	420	854
1002	5	1480	1870	390	834
1002	6	690	1100	410	834
1003	13	630	1050	420	874
1003	17	1430	1850	420	874
1004	15	670	1090	420	874
1004	18	1470	1890	420	874

Remarks:

a. The Regional Specification Card, the first in the program, reserves 100 locations on the drum for the storage of 50 pieces of work. If more locations are desired, this card should be changed. There are over 1600 locations on the drum that could be used for such storage.

b. The reader will notice that the two pieces of work, which are combined to construct a split run, are listed with the same split run number.

c. The reader will notice, that two report time periods (2 x 0.17 = 0.34 hours) are added to the working time of each split run to make up the total time.

d. Split run number "1002" is an example of Discussion (2) (a) which has been explained previously. The pull-out time of the first piece (Sch. No. 5) is not earlier than that of the second piece (Sch. No. 6). So the machine reversed the order of the pieces (i.e., Sch. No. 6 was considered first piece and Sch. No. 5 was considered second piece), and further checks were applied.

Section III

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

1. Presentation

a. Assumptions

In this section the following assumptions are made and included in the body of the program.

(1) (a) A split run is composed of two pieces of work and pay at least 8.00 hours.

(b) The operator gets ten minutes for report time for every piece of work.

(2) (a) Overtime premium is at one and one-half the regular rate.

(b) Overtime is for work in excess of 9.00 hours.

(3) Maximum spread time for a split run is 12:25 hours.

(4) Terminal times and relief times for every straight run is known.

All these assumptions are introduced at the end of the program in the form of words (See Appendix A, Section III). This makes it very simple to change, to fit any special case without any damage to the body of the report. Assumption (4) is introduced in the input data.

b. Flow diagram

(See Figure 5, page 58.)

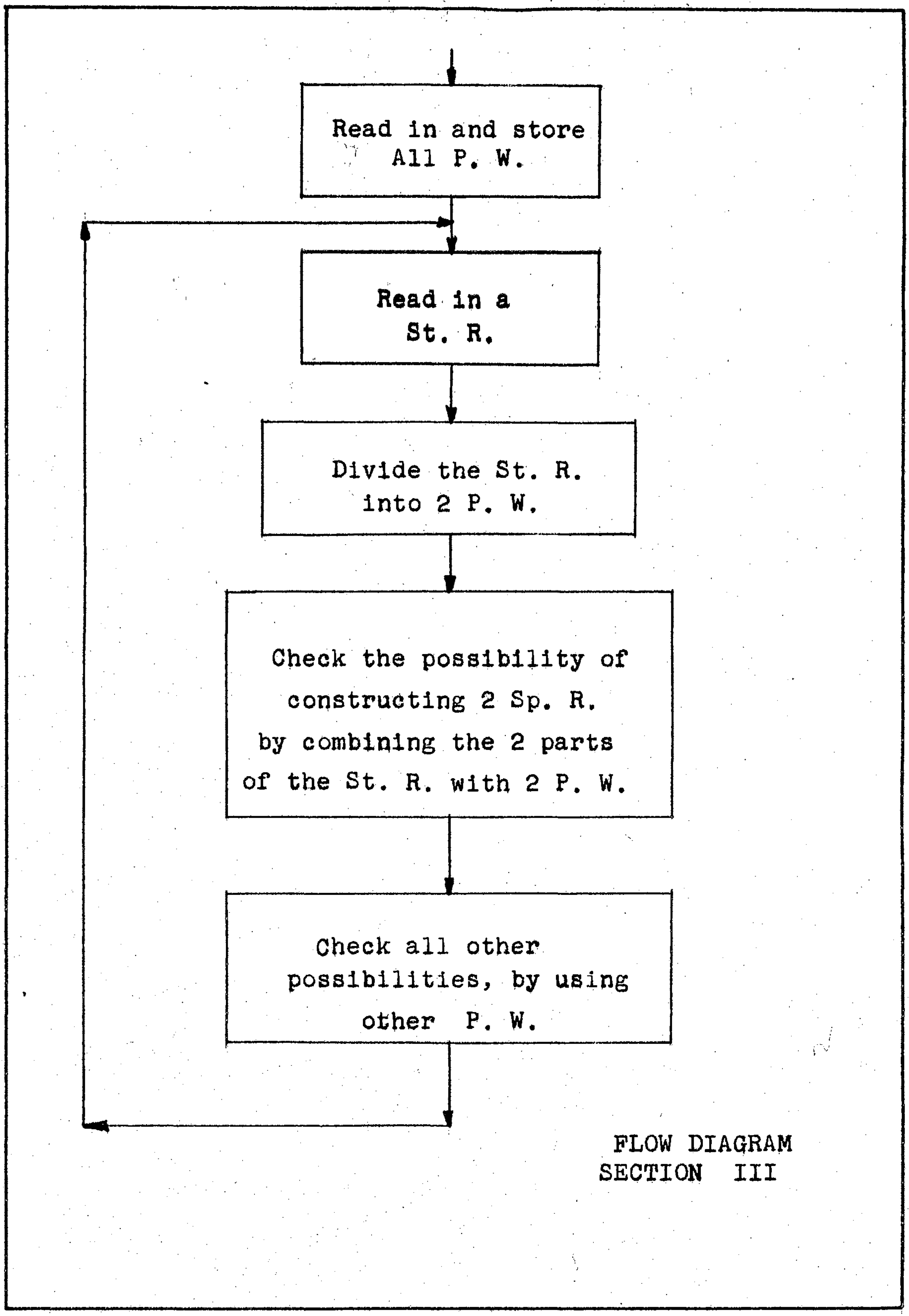

Read in and store
All P. W.
Read in a
St. R.
Divide the St. R.
into 2 P. W.
Check the possibility of
constructing 2 Sp. R.
by combining the 2 parts
of the St. R. with 2 P. W.
Check all other
possibilities, by using
other P. W.
FLOW DIAGRAM
SECTION III

Figure 5

c. Discussion

The program is developed using the "SOAP II" method. It is designed so that the machine will do the following:

(1) The program will cause the machine to store all pieces of work on the drum.

(2) The machine will read in one card (straight run) at a time, divide the total time into two (pieces of work) and check the possibility of constructing two split runs by combining these two pieces of work with another two from those stored on the drum.

(3) The machine will also consider all other possibilities of constructing split runs using other pieces of work stored on the drum and punch out all results.

(4) Although, there are an infinite number of ways to divide an eight hour straight run, yet, it will not be practical to consider all these possibilities. The scheduler should decide on the number of trials desired. For each trial a card is prepared to show the length of one of the two pieces of work into which the straight run will be divided.

(5) Although, a card is prepared to show the length of the first piece of work to which the straight run is to be divided, yet, the machine will first develop a table for all the relief points of this run (as explained in Section I - A) and then divide the run at the relief point which best gives the required division.

(6) The machine will go through the same list of checks mentioned in the discussion of Section II (mainly the length of working time and spread time) when considering split runs constructions.

(7) The machine will consider a solution only if two split runs can be constructed for every straight run being divided.

(8) A table is to be constructed manually, to summarize all the different possibilities from which the final solution for this section is to be selected (will be discussed further at the closing of this section).

2. Preparation of Data

The input data to this section is:

a. An 8-10 card to show the number of locations needed to store information about P.W. on the drum.

b. An 8-10 card to show the number of split runs already constructed in Section II.

c. The 8-10 cards, each showing the length of one of the two pieces of work into which the straight run is to be divided.

d. The 8-10 cards having information about pieces of work to be stored on the drum.

e. The 8-10 cards having straight run information (Section I - A).

Description of input data cards:

a. An 8-10 card to show the number locations needed to store information about P.W. on the drum.

   (1) Columns 1 through 6 will have zeros.

   (2) Columns 7 through 10 will have a number equal to twice the number of P.W.

   (3) Columns 11 through 80 are not used.

b. An 8-10 card to show the number of split runs already constructed in Section II.

   (1) Columns 1 through 6 will have zeros.

   (2) Columns 7 through 10 will have the number of split runs.

   (3) Columns 11 through 80 are not used.

c. The 8-10 cards, each showing the length of one of the two pieces of work to which the straight run is to be divided. In each card:

(1) Columns 1 through 6 will be zeros.

(2) Columns 7 through 10 will be the selected length.

(3) Columns 11 through 80 are not used.

d. The 8-10 cards having information about pieces of work to be stored on the drum. These are a reproduction of the input data to Section II after elimination of those pieces of work which have been used in that section.

e. The 8-10 cards having straight run information. These are a reproduction of the output data to Section I - A, after including information about the terminal and relief times of each run.

(1) Columns 1 through 6, 11 through 16, 21 through 26, 31 through 36, 41 through 46, 51 through 56, 61 through 66, and 71 through 76, are all zeros.

(2) Columns 7 through 10 are for St.R.No.

(3) Columns 17 through 20 are for Sch.No.

(4) Columns 27 through 30 are for P/o Time.

(5) Columns 37 through 40 are for P/in Time.

(6) Columns 47 through 50 are for To.Ti.

(7) Columns 57 through 60 are for Term.Ti.

(8) Columns 67 through 70 are for Relief 1.

(9) Columns 77 through 80 are for Relief 2.

3. Starting the Program

Same as Section I - A, (see page 42).

4. Example and Remarks

Example:

Input data

a. 0000000042

b. 0000001005

c. 0000000200 (This card will be changed with every trial.)

d.

8000260800	14000600	460400	6000200	270900	15000600	470500	11000600
8000280600	8000200	481000	16000600	290700	9000200	491100	17000600
8000580625	9000275	590650	8750225	600650	8250175	610700	8000200
8000621700	19500250	631700	18250125	641600	18500250	651550	18500300
8000661500	18000300	671400	18000400	681300	17000400	691300	18000500
2000701500	20000500						

e.

St.R.No.	Sch.No.	P/o	P/in	To.Ti.	Term.Ti.	Rel.	Rel.
57	37	600	1400	817		25	75
56	36	500	1300	817		25	75
58	38	700	1500	817		25	75
59	39	800	1600	817		25	75
1	3	630	1497	884	10	25	75
2	4	650	1490	857	10	25	75
3	5	670	1480	827	10	25	75
4	6	1100	1890	807		25	75
5	7	500	1310	827	10	25	75
6	7	1445	2300	872		25	75
7	8	520	1330	827	10	25	75
8	8	1465	2320	872		25	75
9	12	610	1420	827	10	25	75
10	12	1420	2230	827		25	75
11	14	1485	2270	802		25	75
12	14	650	1485	852	10	25	75
20	30	590	1400	810	10	25	75

Output data: 0000000200 (First trial)

St.R.No.	Sp.R.No.	Sch.No.	P/o	P/in	To.Ti./P.W.	To.Ti.
57	1006	37	600	800	200	834
	1006	26	800	1400	600	834
57	1007	37	800	1400	600	834
	1007	46	400	600	200	834
57	1008	37	600	800	200	834
	1008	27	900	1500	600	834
57	1009	37	800	1400	600	834
	1009	28	600	800	200	834
57	1010	37	600	800	200	834
	1010	48	1000	1600	600	834
57	1011	37	800	1400	600	834
	1011	61	700	800	200	834
57	1012	37	600	800	200	834
	1012	49	1100	1700	600	834
57	1013	37	800	1400	600	884
	1013	62	1700	1950	250	884
56	1014	36	500	700	200	834
	1014	26	800	1400	600	834
56	1015	36	700	1300	600	884
	1015	64	1600	1850	250	884
58	1016	38	700	900	200	834
	1016	27	900	1500	600	834
58	1017	38	900	1500	600	834
	1017	29	700	900	200	834
58	1018	38	700	900	200	834
	1018	47	500	1100	600	834
58	1019	38	900	1500	600	859
	1019	59	650	875	225	859
58	1020	38	700	900	200	834
	1020	48	1000	1600	600	834
58	1021	38	900	1500	600	809
	1021	60	650	825	175	809
1	1022	3	630	840	210	844
	1022	27	900	1500	600	884
1	1023	3	840	1497	657	816
	1023	63	1700	1825	125	816

St.R.No.	Sp.R.No.	Sch.No.	P/o	P/in	To.Ti./P.W.	To.Ti.
0000000250 (Another trial)						
57	1006	37	600	900	300	834
	1006	69	1300	1800	500	834
57	1007	37	900	1400	500	809
	1007	58	625	900	275	809
58	1008	38	700	1000	300	834
	1008	69	1300	1800	500	834
58	1009	38	1000	1500	500	834
	1009	65	1550	1850	300	834
1	1010	3	630	940	310	844
	1010	69	1300	1800	500	844
1	1011	3	940	1497	557	816
	1011	59	650	875	225	816
2	1012	4	650	960	310	844
	1012	69	1300	1800	500	844
2	1013	4	960	1490	530	814
	1013	62	1700	1950	250	814
3	1014	5	670	980	310	844
	1014	69	1300	1800	500	844
3	1015	5	980	1480	500	834
	1015	66	1500	1800	300	834
12	1016	14	650	960	310	844
	1016	69	1300	1800	500	844
12	1017	14	960	1485	525	809
	1017	64	1600	1850	250	809
0000000300 (Another trial)						
57	1006	37	600	900	300	834
	1006	69	1300	1800	500	834
57	1007	37	900	1400	500	809
	1007	58	625	900	275	809
58	1008	38	700	1000	300	834
	1008	69	1300	1800	500	834
58	1009	38	1000	1500	500	834
	1009	65	1550	1850	300	834

St.R.No.	Sp.R.No.	Sch.No.	P/o	P/in	To.Ti./P.W.	To.Ti.
1	1010	3	630	940	310	844
	1010	69	1300	1800	500	844
1	1011	3	940	1497	557	816
	1011	59	650	875	225	816
2	1012	4	650	960	310	844
	1012	69	1300	1800	500	844
2	1013	4	960	1490	530	814
	1013	62	1700	1950	250	814
3	1014	5	670	980	310	844
	1014	69	1300	1800	500	844
3	1015	5	980	1480	500	834
	1015	66	1500	1800	300	834
12	1016	14	650	960	310	844
	1016	69	1300	1800	500	844
12	1017	14	960	1485	525	809
	1017	64	1600	1850	250	809
0000000350 (Another trial)						
57	1006	37	600	1000	400	834
	1006	68	1300	1700	400	834
57	1007	37	1000	1400	400	834
	1007	67	1400	1800	400	834
0000000400 (Another trial)						
57	1006	37	600	1000	400	834
	1006	68	1300	1700	400	834
57	1007	37	1000	1400	400	834
	1007	67	1400	1800	400	834
0000000450 (Another trial)						
57	1006	37	600	1100	500	834
	1006	66	1500	1800	300	834
57	1007	37	1100	1400	300	834
	1007	70	1500	2000	500	834

St.R.No.	Sp.R.No.	Sch.No.	P/o	P/in	To.Ti./P.W.	To.Ti.
0000000500 (Another trial)						
57	1006	37	600	1100	500	834
	1006	66	1500	1800	300	834
57	1007	37	1100	1400	300	834
	1007	70	1500	2000	500	834
0000000550 (Another trial)						
57	1006	37	600	1200	600	834
	1006	46	400	600	200	834
57	1007	37	1200	1400	200	834
	1007	47	500	1100	600	834
59	1008	39	800	1400	600	834
	1008	46	400	600	200	834
59	1009	39	1400	1600	200	834
	1009	26	800	400	600	834
4	1010	6	1100	1700	600	834
	1010	28	600	800	200	834
4	1011	6	1700	1890	190	824
	1011	27	900	1500	600	824
4	1012	6	1100	1700	600	834
	1012	29	700	900	200	834
4	1013	6	1700	1890	190	824
	1013	48	1000	1600	600	824
4	1014	6	1100	1700	600	859
	1014	59	650	875	225	859
4	1015	6	1700	1890	190	824
	1015	49	1100	1700	600	824
0000000600 (Another trial)						
57	1006	37	600	1200	600	834
	1006	46	400	600	200	834
57	1007	37	1200	1400	200	834
	1007	47	500	1100	600	834

St.R.No.	Sp.R.No.	Sch.No.	P/o	P/in	To.Ti./P.W.	To.Ti.
59	1008	39	800	1400	600	834
	1008	46	400	600	200	834
59	1009	39	1400	1600	200	834
	1009	26	800	1400	600	834
4	1010	6	1100	1700	600	834
	1010	28	600	800	200	834
4	1011	6	1700	1890	190	824
	1011	27	900	1500	600	824
4	1012	6	1100	1700	600	834
	1012	29	700	900	200	834
4	1013	6	1700	1890	190	824
	1013	48	1000	1600	600	824
4	1014	6	1100	1700	600	859
	1014	59	650	875	225	859
4	1015	6	1700	1890	190	824
	1015	49	1100	1700	600	824

Remarks:

a. The reader will notice that when a straight run is divided into two pieces of work, the 0.17 hour report time which was added to the straight run, previously is subtracted. To.Ti. for St.R.No. 57, Sch.No. 37 is 8.17 hours.

When divided into:

St.R.No. 57	Sp.R.No.	1006	Sch.No. 37 is	2.00 h
"	"	1007	Sch.No. 37 is	6.00 h
			The Total Time is	8.00 h

b. The reader will notice that there are several ways of dividing a straight run (Example: St.R. 57), and even when only one trial is considered, there are several combinations leading to several possible split runs. To find the most desirable solution, the following table is constructed:

Horizontally: Schedule numbers of pieces of work

Vertically: Straight run numbers

The same two numbers in each row in the matrix as the number "4" in cell (57, 49) and cell (57, 62) indicates that if straight run "57" is being divided into two pieces of work, and if piece of work "49" is considered to construct a split run, then the piece of work "62" must be also used for the second split run. (A straight run is only divided if two split runs can be constructed.)

The vertical column titled "Total" shows the number of times a straight run was divided and used to construct split runs.

The horizontal row titled "Total" shows the number of times a piece of work was used to construct split runs.

The Method for the Tabular Solution

Since the objective of this section is to schedule as many pieces of work as possible, thus, it is logical to start by considering those pieces of work that could only be scheduled once. The last row in the table shows the number of times a piece of work could be scheduled (according to the program). Therefore, start by considering those cells which have the number "1" (in the last row). But since this solution requires that pieces of work be used in pairs, then when choosing one piece, which could be used once, look for its companion and check the number of times it could be scheduled. If both could only be scheduled once, then this is the only possible schedule for them.

Example:

(1) (a) Piece of work "68" is used once,

P.W. / ST.R.	26	46	27	47	28	48	29	49	58	59	60	61	62	63	64	65	66	67	68	69	70	To.
57	1	1 8	2	8	2	3		4	5			3	4				7	6	6	5	7	8
56	1														1							1
58			1	2		3	(1)			2	3					4				4		4
1			1							2				1						2		2
2													1							1		1
3																	1			1		1
12															1					1		1
59	1	1																				1
4		1		1	2	2		3		3												3
Total	3	4	3	3	2	3	1	2	1	3	1	1	2	1	2	1	2	1	1	6	1	
																		X	X			

(A) (57 and 68) divider 3.50 hours (Sp.R.No. 1006)
(57 and 67) (Sp.R.No. 1007)

Total	2	2	2	2	1	2	1	1	0	3	1	0	1	1	2	1	1	X	X	5	0

(B) (1 and 27) divider 2.00 hours (Sp.R.No. 1022)
(1 and 63) (Sp.R.No. 1023)

Total	2	2	X	2	1	2	0	1	0	2	1	0	1	X	2	1	1	X	X	4	0

PW / ST.R.	26	46	27	47	28	48	29	49	58	59	60	61	62	63	64	65	66	67	68	69	70	To.
57																						0
56	1														1							1
58				2		3				2	3					4				4		3
1																						0
2													1							1		1
3																	1			1		1
12															1					1		1
59	1	1																				1
4		1		1	2	2		3		3												3
Total	2	2	X	2	1	2	0	1	0	2	1	0	1	X	2	1	1	X	X	4	0	
						X					X											

(C) (58 and 48) (58 and 60) divider 2.00 hours (Sp.R.No. 1020) (Sp.R.No. 1021)

Total	2	2	X	1	0	X	0	1	0	1	X	0	1	X	2	0	1	X	X	3	0
								X		X											

(D) (4 and 59) (4 and 49) divider 5.00 hours (Sp.R.No. 1014) (Sp.R.No. 1015)

P.W / ST.R.	26	46	27	47	28	48	29	49	58	59	60	61	62	63	64	65	66	67	68	69	70	To.
57																						0
56	1														(1)							1
58																						0
1																						0
2													1							1		1
3																	1			1		1
12															1					1		1
59	1	1																				1
4																						0
Total	2	1	X	0	0	X	0	X	0	X	X	0	1	X	2	0	1	X	X	3	0	
	X	X																				

(E) (59 and 46) (59 and 26) divider 6.00 hours (Sp.R.No. 1008) (Sp.R.No. 1009)

Total	X	X	X	0	0	X	0	X	0	X	X	0	1	X	1	0	1	X	X	3	0
																	X			X	

(F) (3 and 69) (3 and 66) divider 2.50 hours (Sp.R.No. 1014) (Sp.R.No. 1015) and also its companion piece of work "67" with straight run "57".

(b) Eliminate columns 67, 68, and row 57.

(c) Find the new totals.

(2) (a) Since no other pair of pieces of work are only used once, pieces of work "63" is chosen which is used once and its companion "27", which is used twice.

(b) Eliminate columns 27, 63 and row 1.

(c) Cell (58, 29) has to be taken out of the table since its companion cell (58, 27) was eliminated by eliminating column 27.

(d) Find the new totals.

The previous steps are repeated for (3), (4), (5), and (6). Results from this section (Section III), (Section II) and (Section I - A), combined are a solution to a schedule. Section IV is developed to find the cost of operating a schedule with such a solution.

Section IV

Find the total cost of a schedule.

1. Presentation

a. Assumptions

In this section the following assumptions are made and included in the body of the program.

(1) A run (straight or split) pays at least 8.00 hours.

(2) The operator gets ten minutes for report time for each run or each piece of work.

(3) Overtime premium is at one and one-half the regular rate.

(4) Overtime is for work in excess of 8:50 for straight runs and 9:00 for split runs.

(5) Maximum spread time for a split run is 12.42 hours.

(6) If the spread time is more than 12.42, the operator is paid one-half the excess time at regular pay.

(7) In case of an overtime and a spread penalty, the operator gets either of them which ever pays more.

All these assumptions could be changed to fit any special case without any damaging to the body of the program.

b. Flow diagram

(See Figure 6, page 78.)

c. Discussion

The program is developed using the "FOR TRANSIT" method. It is designed so that the machine will do the following:

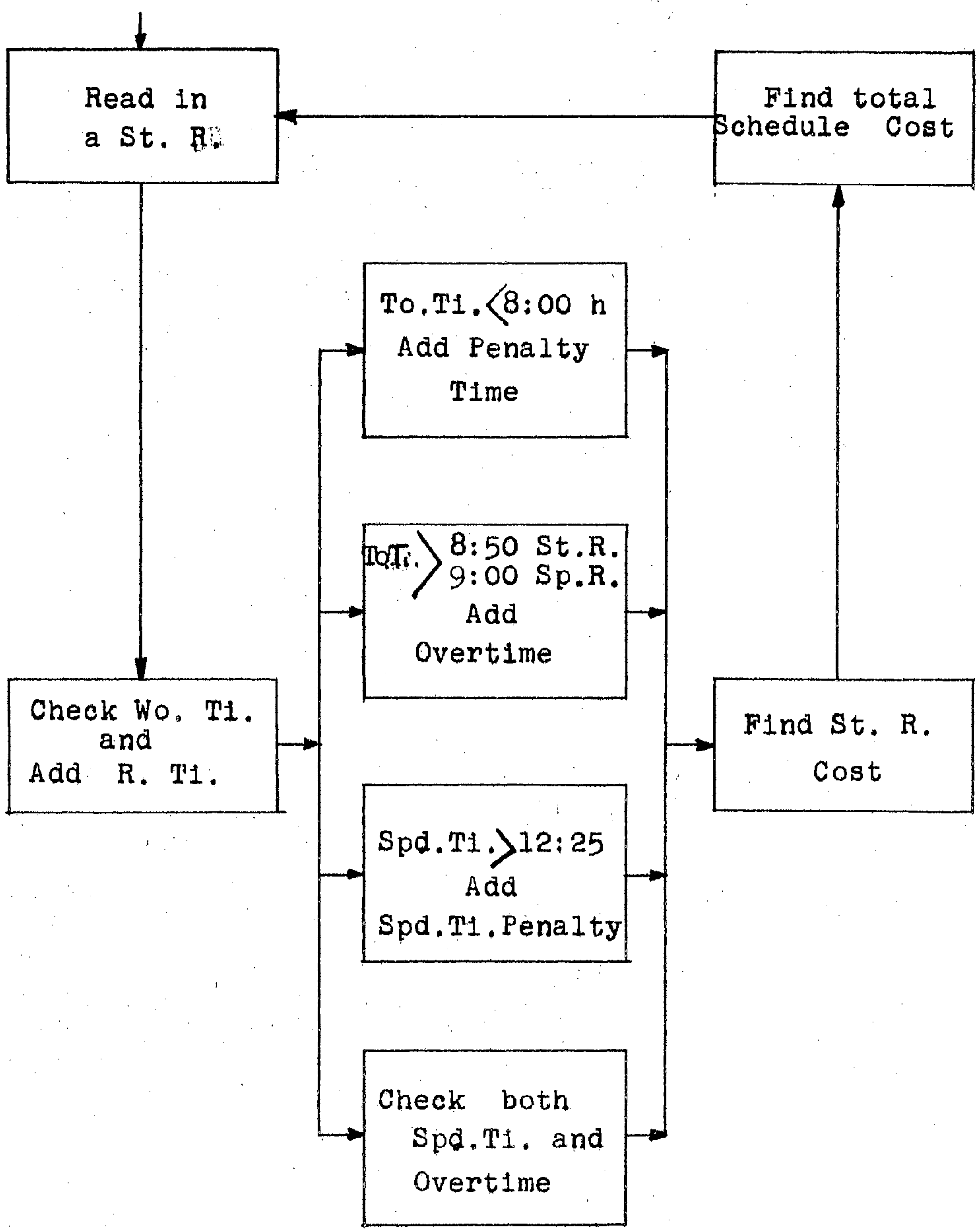
(1) Check the operator assignment and add ten minutes for report time for every straight run or ten minutes for each piece of work in a split run.

(2) Check the total time of an assignment for the minimum hours requirement. If less than 8.00 hours, the machine will add a penalty time and pays the operator for 8.00 hours.

(3) Check the total time of an assignment for an overtime. In case an overtime exists, the machine will figure the pay for both the regular period and the overtime period and add them.

(4) Check the spread time for the maximum permissible. If the spread time is in excess of the maximum, the machine will add a penalty time of one-half the excess time at regular pay.

(5) Check if both an overtime and a spread



FLOW DIAGRAM
SECTION IV

Figure 6

time exists. If so, the machine will compute both, and finds which is larger and add it to the regular pay.

2. Preparation of Data

Since the "Floating Point" system is used, an 8-10 (eight word load card) standard card is used.

a. An 8-10 card to show both the number of runs to be evaluated to find their cost and the operators pay rate per hour.

(1) Columns 1 through 6 will have zeros.

(2) Columns 7 through 10 will have the number of runs.

(3) Columns 11 through 18 will show the pay rate.

(4) Columns 19 and 20 for decimal point identification.

b. The 8-10 cards each to show the working time, the number of pieces, and the spread time of each run.

(1) Columns 1 through 8 to show the working time.

(2) Columns 9 and 10 for decimal point identification.

(3) Columns 11 to show number of pieces of work in the run.

time exists. If so, the machine will compute both, and finds which is larger and add it to the regular pay.

2. Preparation of Data

Since the "Floating Point" system is used, an 8-10 (eight word load card) standard card is used.

a. An 8-10 card to show both the number of runs to be evaluated to find their cost and the operators pay rate per hour.

(1) Columns 1 through 6 will have zeros.

(2) Columns 7 through 10 will have the number of runs.

(3) Columns 11 through 18 will show the pay rate.

(4) Columns 19 and 20 for decimal point identification.

b. The 8-10 cards each to show the working time, the number of pieces, and the spread time of each run.

(1) Columns 1 through 8 to show the working time.

(2) Columns 9 and 10 for decimal point identification.

(3) Columns 11 to show number of pieces of work in the run.

(4) Columns 12 through 18 are to have zeros.

(5) Columns 19 through 20 for decimal point identification.

(6) Columns 21 through 28 to show spread time.

(7) Columns 29 and 30 for decimal point identification.

3. Starting the Program

The "FOR TRANSIT" method has been used in developing this section, therefore, the steps to follow on the machine are those of any ordinary For Transit program and may be summarized in the following phases:

Phase I Translation

Phase II Compilation

Phase III Assembly

Phase IV Using the object program

(For the switches and console settings and machine operation, see an I.B.M. Reference manual for "FOR TRANSIT".)

4. Example and Remarks

Example:

Input data

No. of runs	Pay rate
0000000034	2000000051

Wo. Ti.	No. of P.W.	Spd. Ti.	
8470000051	1000000051	8470000051	
7880000051	1000000051	7880000051	
8050000051	1000000051	8050000051	
7700000051	1000000051	7700000051	run (a)
8100000051	1000000051	8100000051	
7920000051	1000000051	7920000051	
7920000051	2000000051	1225000052	
8300000051	2000000051	9970000051	
7680000051	2000000051	1020000052	
7870000051	2000000051	1128000052	run (b)
7730000051	2000000051	1198000052	
8420000051	2000000051	9580000051	
7700000051	2000000051	1267000052	run (c)
8110000051	2000000051	1215000052	
8110000051	2000000051	1167000052	
8150000051	2000000051	1070000052	
8180000051	3000000051	1127000052	
7970000051	3000000051	1160000052	
7530000051	2000000051	1225000052	
8130000051	1000000051	8130000051	
8320000051	1000000051	8320000051	
8270000051	1000000051	8270000051	
8030000051	1000000051	8030000051	
7830000051	1000000051	7830000051	
7750000051	1000000051	7750000051	
7700000051	1000000051	7700000051	
9670000051	2000000051	1100000052	run (d)
8670000051	2000000051	1442000052	
9670000051	2000000051	1442000052	run (e)
9670000051	2000000051	1542000052	
9670000051	2000000051	1642000052	
7000000051	2000000051	1100000052	
7000000051	2000000051	1442000052	

Output data

Cost in $	Wo. Ti.	No. of P.W.	Spd. Ti.
1728000052	8470000051	1000000051	8470000051
1728000052			
1610000052	7880000051	1000000051	7880000051
3338000052			
1644000052	8050000051	1000000051	8050000051
4982000052	——Total cost including all previous runs.		

Cost in $	Wo. Ti.	No. of P.W.	Spd. Ti.	
1600000052	7700000051	1000000051	7700000051	run (a)
6582000052				
1654000052	8100000051	1000000051	8100000051	
8236000052				
1758000052	8620000051	1000000051	8620000051	
9994000052				
1618000052	7920000051	1000000051	7920000051	
1161200053				
1652000052	7920000051	2000000051	1225000052	
1326400053				
1728000052	8300000051	2000000051	9970000051	
1499200053				
1604000052	7680000051	2000000051	1020000052	
1659600053				
1642000052	7870000051	2000000051	1128000052	run (b)
1823800053				
1614000052	7730000051	2000000051	1198000052	
1985200053				
1752000052	8420000051	2000000051	9580000051	
2160400053				
1633000052	7700000051	2000000051	1267000052	run (c)
2323700053				
1690000052	8110000051	2000000051	1215000052	
2492700053				
1690000052	8110000051	2000000051	1167000052	
2661700053				
1698000052	8150000051	2000000051	1070000052	
2831500053				
1738000052	8180000051	3000000051	1127000052	
3005300053				
1696000052	7970000051	3000000051	1160000052	
3174900053				
1600000052	7530000051	2000000051	1225000052	
3334900053				
1660000052	8130000051	1000000051	8130000051	
3500900053				
1698000052	8320000051	1000000051	8320000051	
3670700053				
1688000052	8270000051	1000000051	8270000051	
3839500053				
1640000052	8030000051	1000000051	8030000051	
4003500053				
1600000052	7830000051	1000000051	7830000051	
4163500053				
1600000052	7750000051	1000000051	7750000051	
4323500053				
1600000052	7770000051	1000000051	7770000051	
4483500053				
2103000052	9670000051	2000000051	1100000052	run (d)
4697000053	——Total cost including all previous runs.			

Cost in $	Wo. Ti.	No. of P.W.	Spd. Ti.	
2002000052	8670000051	2000000051	1442000052	
4897200053				
2103000052	9670000051	2000000051	1442000052	run (e)
5110700053				
2103000052	9670000051	2000000051	1542000052	
5324200053				
2202000052	9670000051	2000000051	1642000052	
5544400053				
1600000052	7000000051	2000000051	1100000052	
5704400053				
1800000052	7000000051	2000000051	1442000052	
5884400053——Total cost including all previous runs.				

Remarks:

To further explain this section, the reader is asked to refer to those runs marked (a, b, c...) on page 81 and their costs on pages 82 and 83.

Run (a) Working time is 7.70 hours plus 0.17 report time equals 7.87 hours which is less the 8 hour (minimum pay). The reader will notice that machine evaluated the cost of this run on the 8 hours minimum.

Run (b) The reader will notice that two report time periods of 0.34 hour had been added to the working time 7.87, and the run is evaluated to cost $16.42.

Run (c) The cost was found to be $16.33. This is based on:

7.70 working time
0.34 report time (two periods)
0.125 spread penalty (one-half the excess time of 12.67 - 12.42)
8.165 hours at a rate of $2.00/hour.

= $16.33

Run (d) The cost was found to be $21.03. This is based on:

9.67 working time
0.34 report time (two periods)
10.01 Total

9.00 x 2 = $18.00 regular pay
1.01 x 3 = $ 3.03 (1.5) regular pay
$21.03 Total

Run (e) Working time of this run is equal to the working time of (d), but the spread time is beyond the maximum permissible. Evaluating the overtime and the spread penalty, they were found to be \$3.03 and 2.00. The larger was chosen; the run was evaluated to cost \$21.03.

CHAPTER V

SUMMARY AND CONCLUSIONS

The transit operator assignment problem has been divided into four sections. This division has been arranged in a manner that all (or a portion) of the output information from one section is the input information to the succeeding section. This, besides cutting down on almost all clerical work, made it easier and more convenient to study and analyze each section separately from the whole problem.

The four sections are:

Section I

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

B. An intermediate step is necessary to change the format by which pieces of work are punched out (Section I - A) to the appropriate form needed as input data for Section II.

Section II

Split runs are constructed by combining pieces of work.

Section III

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

Section IV

Find the total cost of a schedule.

A program was written for each section which will compute and construct the requirements of each section. Range limits are established in advance and set up as controls in the program. The total man-hours' schedule are first divided on a single route basis; then pieces of work which cannot be arranged in proper order are integrated in other routes. Thus, an operator may work on two different routes in completing a daily run assignment. These four programs would give a solution with as many straight runs as possible and a minimum number of unscheduled pieces of work.

Such questions as, "How much of a service mileage reduction should be expected?" "Will the staff be reduced (in the existing scheduling department)?" and "How much will the savings in dollars be?", might be raised. Unfortunately, these questions cannot be answered exactly until this new method of scheduling is put to work. However, the author feels that a reduction of five percent could be expected in the service mileage. A staff reduction of approximately 50% might be expected easily. Such a figure has been found to be normal in similar operations in which the digital computer substituted clerical work.

As to the savings in dollars, the author believes the following calculations could represent closely an actual case.

A city transit company with 100 buses on the road daily, would need about two men for two months to develop the operator assignments.

Two men for two months = 2 x 2 x(4 x 40)

= 640 man hours

at a $3.00 average/man hour.

Total cost = 3 x 640

= 1920 dollars

Using the digital computer, the same firm would need:

Time	Machine	Labor	Rate	Total Cost
1 hour	Card punching	-	$ 1.00	1.00
1 hour	-	"	2.50	2.50
1 hour	650	-	100.00	100.00
2 hours	-	"	4.00	8.00
				$111.50

These rates are based on the college computer facilities rates. On these bases savings are $1808.50

= 1800.00 dollars.

Industry rates are about three times as much as college rates which would net savings of about $1580.

If such a firm had three schedules per year, this new method could net a saving of at least $4740 a year. This does not include the convenience and easiness of scheduling which could result that such firms might increase the number of schedules per year, and the capability of develping a schedule on a short time notice.

It is the feeling of the author that certain improvements could be applied to this program of scheduling operator assignment, depending on the specific requirements of transit companies and their labor contracts. As an example, some labor contracts would allow constructing a split run from three pieces of work or different spread times.

It is also the belief of the author that a digital computer program could be developed to substitute the tabular solution found in Section III, pages 72, 73, and 74. Further research could show that the techniques of linear programing might apply.

BIBLIOGRAPHY

Beckman, Martin. Studies in the Economic of Transportation. New Haven: Yale University Press, 1956.

Editors of Fortune. The Exploding Metropolis. Garden City, New York: Doubleday and Company, 1957.

Foulkes, J. W. "On Bus Schedules." Management Science, I, 41.

Gilmore, Welch Harlan. Transportation and the Growth of Cities. Illinois: Free Press, 1953.

Owen, Wilfred. Automotive Transportation; Trends and Problems. Washington: Brookings Institution, 1949.

Reck, Franklin Mering. A Car Traveling People. Detroit: Automobile Manufacturers Association, 1945.

Richardson, E. B. "Evaluation of Bus Requirements for City Service." S.A.E. Journal, (March, 1952), 60-67.

Taff, Charles Albert. Commercial Motor Transportation. Illinois: Richard D. Irwin, 1955.

__________. "The Trials of U.S. Commuters." Time, (January 18, 1960), 74-78.

__________. "Data Logging Locates Lost Buses." Control Engineer, (June, 1958), 125.

__________. "How Computers Can Simplify Bus Scheduling." Fleet Owner, (October, 1957), 322.

__________. "What Will Transportation Be Like Ten Years In The Future." Bus Transportation, (January, 1956), 28-31.

APPENDIX A

PROGRAM LISTING

Section I

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

```
                  BLR    0050     0150
                  BLR    0000     0050
   1
        START     RCD    9006
                  RAU    8002
                  RAU    8002
                  STU    SCHNO    AGAIN
        AGAIN     RAU    9007
                  NZU    EXIT1    START
        EXIT1     RAU    9008
                  NZU    EXIT2    START
        EXIT2     SUP    9007
                  STU    9009
                  SUP    WORD1
                  NZU    OUT02    OUT01
        OUT01     AXA    0001
                  LDD    8005
                  STD    9005
                  RAU    9009
                  AUP    WORD2
                  STU    9009
                  PCH    9005     START
   1
        OUT02     BMI    OUT03    OUT04
        OUT03     RAU    8002
                  RAU    8002
                  STU    9005
                  PCH    9005     START
   1
        OUT04     RAU    9009
                  SUP    WORD3
                  NZU    OUT05    OUT01
   1
        OUT05     BMI    OUT01    OUT06
```

```
1
        OUT06   RAU   SCHNO
                SUP    9006
                NZU   TABLE      GOON5
        TABLE   RAC    0000
                RAU    9007
                STU    6000
                AXC    0001
                AUP   TERMI      LOOP1
        LOOP1   STU    6000
                SUP    9008
                BMI   GOON1      CONTI
        GOON1   NZU   GOON2      CONT1
        GOON2   AUP    9008
                AUP   RELF1
                AXC    0001
                STU    6000
                SUP    9008
                BMI   GOON3      CONTI
        GOON3   NZU   GOON4      CONT1
        GOON4   AUP    9008
                AUP   RELF2
                AUX    0001      LOOP1
1
        CONT1   ACX    0001
                LDD   NINE
                STD    6000      GOON5
1
        GOON5   RAU    8006
                NZU   OUT80      OUT07
1
        OUT07   AXB    0001
1
                RAU    9007
                AUP   WORD1
                STU   W11
                LDD   W11
                TLU    0000
                SRT    0004
                RAC    8002
                LDD    6000
                STD   W12
                SXC    0001
                LDD    6000
                STD   W10
1
                RAU   W12
                SUP   W11
                NZU   OUTR2      OUTR1
        OUTR2   SUP   WORD4
                BMI   OUTR3      OUTR4
```

```
        OUTR4   MPY   WORD5
                SRD    0001
                STL   X1
                RAU   W11
                SUP   W10
                SUP   X1
                BMI   OUTR5       OUTR3
1
        OUTR1   AXA    0001
                LDD    8005
                STD    9015
                LDD    9006
                STD    9016
                LDD    9007
                STD    9017
                LDD   W12
                STD    9018
                RAU   WORD1
                AUP   WORD2
                STU    9019
                PCH    9015
                LDD   W12
                STD    9007       AGAIN
1
        OUTR3   AXA    0001
                LDD    8005
                STD    9015
                LDD    9006
                STD    9016
                LDD    9007
                STD    9017
                LDD   W12
                STD    9018
                RAU   W12
                SUP    9007
                AUP   WORD2
                STU    9019
                PCH    9015
                LDD   W12
                STD    9007       AGAIN
1
        OUTR5   AXA    0001
                LDD    8005
                STD    9015
                LDD    9006
                STD    9016
                LDD    9007
                STD    9017
                LDD   W10
                STD    9018
                RAU   W10
```

```
               SUP   9007
               AUP   WORD2
               STU   9019
               PCH   9015
               LDD   W10
               STD   9007      AGAIN
1
       OUT80   SXB   0001
               RAU   9008
               SUP   WORD1
               STU   W11
               LDD   W11
               TLU   0000
               SRT   0004
               RAC   8002
               LDD   6000
               STD   W12
               SXC   0001
               LDD   6000
               STD   W10
1
               RAU   W12
               SUP   W11
               STU   X3
               NZU   OUTR6     OUTR7
       OUTR6   RAU   W11
               SUP   W10
               SUP   WORD4
               BMI   OUTR9     OUTR8
       OUTR8   MPY   WORD5
               SRD   0001
               STL   X4
               RAU   X4
               SUP   X3
               BMI   OUTR9     OUTR0
       OUTR7   AXA   0001
               LDD   8005
               STD   9015
               LDD   9006
               STD   9016
               LDD   W12
               STD   9017
               LDD   9008
               STD   9018
               RAU   WORD1
               AUP   WORD2
               STU   9019
               PCH   9015
               LDD   W12
               STD   9008      AGAIN
1
       OUTR9   AXA   0001
```

```
                 LDD   8005
                 STD   9015
                 LDD   9006
                 STD   9016
                 LDD  W10
                 STD   9017
                 LDD   9008
                 STD   9018
                 RAU   9008
                 SUP  W10
                 AUP  WORD2
                 STU   9019
                 PCH   9015
                 LDD  W10
                 STD   9008     AGAIN
1
         OUTRO   AXA   0001
                 LDD   8005
                 STD   9015
                 LDD   9006
                 STD   9016
                 LDD  W12
                 STD   9017
                 LDD   9008
                 STD   9018
                 RAU   9008
                 SUP  W12
                 AUP  WORD2
                 STU   9019
                 PCH   9015
                 LDD  W12
                 STD   9008     AGAIN
1        WORDS
         TERMI                     10
         RELF1                     25
         RELF2                     75
         NINE     99   9999      9999
         WORD1                    783
         WORD2                     17
         WORD3                    867
         WORD4                     85
         WORD5                    150
```

Section I

B. An intermediate step is necessary to change the format by which pieces of work are punched out (Section I - A), to the appropriate form needed as input data for Section II.

```
START   RAA   0000
        RAC   0009
        RCD   9001
        LDD   9001
        RAB   8001     READ
READ    RCD   9006
        SXB   0001
        NZB   OUT10    OUT11
OUT10   AXA   0002
        SXA   0008
        NZA   OUT12    OUT13
OUT12   AXA   0008
        RAL   9008
        SLT   0004
        ALO   9009
        STL   9010 C
        SXC   0001
        RAL   9006
        SLT   0004
        ALO   9007
        STL   9010 C
        SXC   0001     READ
OUT13   AXA   0008     OUT14
OUT14   RAL   9008
        SLT   0004
        ALO   9009
        STL   9010 C
        SXC   0001
        RAL   8005
        SLT   0005
        ALO   9006
        SLT   0004
        ALO   9007
        STL   9010 C
        RAA   0000     PUNCH
OUT11   AXA   0002     OUT14
PUNCH   PCH   9010 C
        RAC   0009     READ
```

Section II

Split runs are constructed by combining pieces of work.

```
                  REG   P0100       0200
1
        BEGIN     RAA    0000
                  RAB    1000       START
        START     RCD    9002
                  SET    9002
                  SIB   P0001  A
                  RAL    9002
                  SLT    0001
                  AXA    8003
                  RAU   NUMB
                  SXA    8003
                  NZA   OUT1        OUT2
        OUT1      AXA    8003       START
1
        OUT2      RAU    8005
                  STU   INDEX       OUT3
        OUT3      RAL   P0001  A
                  NZE   OUT4        OUT5
        OUT5      AXA    0002
                  LDD   NUMB
                  SXA    8001
                  NZA   OUT6        START
        OUT6      LDD   NUMB
                  AXA    8001       OUT2
1
        OUT4      SLT    0001
                  RAL    8002
                  SLT    0005
                  STU    9005
                  RAL    8002
                  SLT    0004
                  STU    9006
                  RAL   P0002  A
                  SLT    0001
                  RAL    8002
                  SLT    0005
                  STU    9007
                  RAL    8002
                  SLT    0004
                  STU    9008       REPET
```

```
1
      REPET   AXA    0002
              LDD   NUMB
              SXA    8001
              NZA   OUT7         BACK
      OUT7    LDD   NUMB
              AXA    8001
1
              RAL   P0001  A
              NZE   OUT8         REPET
      OUT8    SLT    0001
              RAL    8002
              SLT    0005
              STU    9015
              RAL    8002
              SLT    0004
              STU    9016
              RAL   P0002  A
              SLT    0001
              RAL    8002
              SLT    0005
              STU    9017
              RAL    8002
              SLT    0004
              STU    9018
1
              RAU    9016
              SUP    9006
              NZU   OUT9         REPET
      OUT9    BMI   RVERS        OUT10
1
      OUT10   RAU    9017
              SUP    9006
              SUP   SPRED
              NZU   OUT11        GOON1
      OUT11   BMI   GOON1        REPET
1
      GOON1   RAU    9016
              SUP    9007
              BMI   REPET        OUT12
      OUT12   RAU    9008
              AUP    9018
              SUP   WORD1
              NZU   OUT13        PUNCH
      OUT13   BMI   REPET        OUT14
      OUT14   AUP   WORD1
              SUP   WORD3
              NZU   OUT15        PUNCH
      OUT15   BMI   PUNCH        REPET
1
```

```
        PUNCH  AXB  0001
               LDD  8006
               STD  9004
               STD  9014
               RAU  9008
               AUP  9018
               AUP  WORD2
               AUP  WORD2
               STU  9009
               PCH  9004
               STU  9019
               PCH  9014
               RAU  8002
               STL  P0001 A
               STL  P0002 A    BACK
1
        BACK   RAU  INDEX
               RAA  8003
               AXA  0002
               RAU  8005
               STU  INDEX
               LDD  NUMB
               SXA  8001
               NZU  OUT18      START
        OUT18  LDD  NUMB
               AXA  8001       OUT3
1
        RVERS  RAU  9007
               SUP  9016
               SUP  SPRED
               NZU  OUT17      GOON2
        OUT17  BMI  GOON2      REPET
        GOON2  RAU  9006
               SUP  9017
               BMI  REPET      OUT12
1       WORDS
        SPRED                   1242
        WORD1                    766
        WORD2                     17
        WORD3  NOP  0000        0866
        NUMB                      20
```

Section III

Split runs are constructed by breaking straight runs, Section I - A, and combining their pieces with those pieces of work that were not scheduled in Section II.

```
1
                BLR   1500        1600
                BLR   0000        0050
                REG   P0100       0199
                REG   R0200       0299
1
      STRAT     RCD   9002
                LDD   9002
                STD   NUMBR
                RAA   0000
                RAB   0000
                RCD   9002
                LDD   9002
                AXB   8001        OUTO
      OUTO      RCD   9002
                SET   9002
                SIB   P0001 A
                RAL   9002
                SLT   0001
                AXA   8003
                RAU   NUMBR
                SXA   8003
                NZA   OUT1        OUT2
      OUT1      AXA   8003        OUTO
1
      OUT2      RCD   9002
                LDD   9002
                STD   PIECE       READ
1
      READ      RCD   9051
                RAC   0000
                RAU   9053
                STU   6000
                AXC   0001
                AUP   9056        LOOP1
      LOOP1     STU   6000
                SUP   9054
```

```
            BMI   GOON1    CONT1
      GOON1 NZU   GOON2    CONT1
      GOON2 AUP    9054
            AUP    9057
            AXC    0001
            STU    6000
            SUP    9054
            BMI   GOON3    CONT1
      GOON3 NZU   GOON4    CONT1
      GOON4 AUP    9054
            AUP    9058
            AXC    0001    LOOP1
      CONT1 AXC    0001
            LDD   NINE
            STD    6000
1
            RAU    9053
            AUP   PIECE
            STU   W11
            LDD   W11
            TLU    0000
            SRT    0004
            RAC    8002
            LDD    6000
            STD   W12
            LDD    9051
            STD    9013
            STD    9033
            LDD    9052
            STD    9015
            STD    9035
            LDD    9053
            STD    9016
            LDD   W12
            STD    9017
            STD    9036
            LDD    9054
            STD    9037
            RAU    9017
            SUP    9016
            STU    9018
            RAU    9037
            SUP    9036
            STU    9038    OUT3
1
      OUT3  RAA    0000    OUT40
      OUT40 RAL   P0001 A
            NZE   OUT6     OUT4
      OUT4  AXA    0002
            LDD   NUMBR
            SXA    8001
```

```
                 NZA   OUT7      READ
         OUT7    LDD   NUMBR
                 AXA    8001     OUT40
         OUT6    SLT    0001
                 RAL    8002
                 SLT    0005
                 STU    9025
                 RAL    8002
                 SLT    0004
                 STU    9026
                 RAL   P0002 A
                 SLT    0001
                 RAL    8002
                 SLT    0005
                 STU    9027
                 RAL    8002
                 SLT    0004
                 STU    9028
1
                 RAU    9026
                 SUP    9016
                 NZU   OUT9      OUT4
         OUT9    BMI   RVERS     OUT10
1
         OUT10   RAU    9027
                 SUP    9016
                 SUP   SPRED
                 NZU   OUT11     GOON5
         OUT11   BMI   GOON5     OUT4
1
         GOON5   RAU    9026
                 SUP    9017
                 BMI   OUT4      OUT12
1
         OUT12   RAU    9018
                 AUP    9028
                 SUP   WORD1
                 NZU   OUT13     READY
         OUT13   BMI   OUT4      OUT14
         OUT14   AUP   WORD1
                 SUP   WORD3
                 NZU   OUT15     READY
         OUT15   BMI   READY     OUT4
1
         READY   RAU   P0001 A
                 STU   R0001 A
                 STL   P0001 A
                 RAU   P0002 A
                 STU   R0002 A
                 STL   P0002 A
1
```

```
              RAU   8005
              STU   AAAAA       OUT50
       OUT50  RAA   0000        OUT51
1
       OUT17  AXA   0002
              LDD   NUMBR
              SXA   8001
              NZA   OUT16       OUT21
       OUT16  LDD   NUMBR
              AXA   8001        OUT51
       OUT51  RAL   P0001 A
              NZE   OUT18       OUT17
       OUT18  SLT   0001
              RAL   8002
              SLT   0005
              STU   9045
              RAL   8002
              SLT   0004
              STU   9046
              RAL   P0002 A
              SLT   0001
              RAL   8002
              SLT   0005
              STU   9047
              RAL   8002
              SLT   0004
              STU   9048
1
              RAU   9046
              SUP   9036
              NZU   OUT22       OUT17
       OUT22  BMI   OUT23       OUT24
1
       OUT24  RAU   9047
              SUP   9036
              SUP   SPRED
              NZU   OUT25       GOON6
       OUT25  BMI   GOON6       OUT17
1
       GOON6  RAU   9046
              SUP   9037
              BMI   OUT17       OUT26
1
       OUT26  RAU   9038
              AUP   9048
              SUP   WORD1
              NZU   OUT27       PUNCH
       OUT27  BMI   OUT17       OUT28
       OUT28  AUP   WORD1
              SUP   WORD3
              NZU   OUT29       PUNCH
```

```
      OUT29  BMI   PUNCH      OUT17
1
      PUNCH  RAU    8002
             STL   P0001 A
             STL   P0002 A
             RAU    9018
             AUP    9028
             AUP   WORD2
             AUP   WORD2
             STU    9019
             STU    9029
             RAU    9038
             AUP    9048
             AUP   WORD2
             AUP   WORD2
             STU    9039
             STU    9049
             AXB    0001
             RAU    8006
             STU    9014
             PCH    9013
             STU    9024
             PCH    9023
             AXB    0001
             RAU    8006
             STU    9034
             PCH    9033
             STU    9044
             PCH    9043      OUT21
1
      OUT21  RAU   AAAAA
             RAA    8003
             RAU   R0001 A
             STU   P0001 A
             RAU   R0002 A
             STU   P0002 A    OUT4
1
      RVERS  RAU    9017
             SUP    9026
             SUP   SPRED
             NZU   OUT30      OUT31
      OUT30  BMI   OUT31      OUT4
      OUT31  RAU    9016
             SUP    9027
             BMI   OUT4       OUT12
1     OUT23
      OUT23  RAU    9037
             SUP    9046
             SUP   SPRED
             NZU   OUT32      OUT33
      OUT32  BMI   OUT33      OUT17
```

```
          OUT33   RAU   9036
                  SUP   9047
                  BMI   OUT17      OUT26
     1    WORDS
          NINE     99   9999       9999
          WORD1                     766
          WORD2                      17
          WORD3                     866
          SPRED                    1242
```

Section IV

Finding the total cost of a schedule.

```
C 0000 0
     1 0 T=0.00
     2 0 DIMENSION A(150),P(150),S(150)
     2 1 ,C(150)
     3 0 READ,N,H
     4 0 DO 28 I=1,N
     5 0 READ,A(I),P(I),S(I)
         IF (A(I)+P(I)*(.17)-8.0)6,6,11
     6 0 X=(S(I)-12.42)
         IF(X)7,7,9
     7 0 C(I)=(8.0)*H
     8 0 GO TO 25
     9 0 C(I)=(8.0+(.5)*X)*H
    10 0 GO TO 25
    11 0 CONTINUE
         IF(A(I)-8.67)12,12,17
    12 0 X=(S(I)-12.42)
         IF(X)13,13,15
    13 0 C(I)=(A(I)+P(I)*(.17))*H
    14 0 GO TO 25
    15 0 C(I)=(A(I)+P(I)*(.17)+(.5)*X)
    15 1 *H
    16 0 GO TO 25
    17 0 X=(S(I)-12.42)
         IF(X)18,18,20
    18 0 C(I)=((1.5)*(A(I)+P(I)*(.17))
    18 1 -4.5)*H
    19 0 GO TO 25
    20 0 B=(8.67+P(I)*(.17)+(.5)*X)*H
    21 0 D=((1.5)*(A(I)+P(I)*(.17))
    21 1 -4.5)*H
         IF (B-D)22,22,24
    22 0 C(I)=D
    23 0 GO TO 25
    24 0 C(I)=B
    25 0 PUNCH,C(I),A(I),P(I),S(I)
    26 0 T=T+C(I)
    27 0 PUNCH,T
    28 0 CONTINUE
         END
```

APPENDIX B

LABOR MANAGEMENT CONTRACT ON SCHEDULING RESTRICTIONS

The following is a sample of the restrictions that are generally found in a Labor Management Contract that govern the operator assignment in transit operations. As the same labor union represents the operators in most transit companies, these clauses should be nearly identical in most contracts.

1. A straight run is defined as a run so constructed as to be composed of continuous hours of pay.
2. A split run is defined as a run so constructed as to be composed of two or more pieces of work with an unpaid interval or intervals between such pieces of work.
3. All regularly assigned runs shall pay not less than eight (8) hours excluding preparatory time.
4. Straight runs as herein defined shall be not less than thirty five percent (35%) of all regularly assigned runs. The company agrees that no schedule will be broken into pieces from which a straight run could be created unless at least two combination or split runs can be made in piece of a straight run.

5. Split runs as herein defined may be constructed so as to contain a spread of hours in excess of twelve (12) hours and twenty-five (25) minutes. Ten percent (10%) of all regularly assigned runs may be constructed so as to contain a spread of hours in excess of thirteen (13) hours and twenty five (25) minutes; provided, however, that intervals of fifteen (15) minutes or less shall be paid for and considered time worked, and providing further that each piece of work used in constructing a split run shall pay at least (2) hours pay time, and providing further that time in excess of the spread set forth above shall be paid for at one-half (1/2) of the straight time hourly rate of pay.

6. Split runs shall not be constructed so as to contain in excess of two (2) unpaid intervals between pieces of work.

7. All motor coach operators on pull-outs or reliefs shall be required to show up at the Dispatcher's Office or relief point ten (10) minutes before their run starts.

8. All motor coach operators shall be required to deliver their respective buses to the garage, but shall not be required to wait for the gassing of said buses but shall be relieved of all duties in connection with both the gassing and the parking of said buses.

9. If A.M. or P.M. motor coach operators are called for extra work during the day, they will not be required to take their regular runs until they have had eight (8) hours off duty, except in cases of emergency.

10. The extra board shall carry sufficient employees, both white and colored, to adequately take care of the employees; leaves of absence, vacations, and sickness. The extra board shall work first-up and first out, and shall rotate on eight (8) hours received in any one (1) day. All regular and split runs shall be caught off the board according to number. If extra employees sleep in, they shall be placed at the bottom of the extra board. All extra or special runs will be protected by the extra board. If any extra motor coach operator catches a run due to a change of schedule, they will hold that run until the shift is completed.

11. If an extra motor coach operator is run around only that motor coach operator shall be paid for any loss of time due to the run around. If used on another piece of work then the pay time of this piece of work shall be used in making up the run around time.

12. If the extra board operator works a night shift, he shall not be required to work the following day without having had eight (8) hours off duty, except in cases of emergency.

13. All motor coach operators shall receive ten (10) minutes preparatory time for each piece of work. Preparatory time as above provided for, or any part thereof, may be included within, and made a part of, any minimum guarantee of pay time provided for in this agreement.

14. All motor coach operators who are assigned to extra work shall receive a minimum of two and one-half ($2\frac{1}{2}$) hours of pay time at their regular straight time hourly rate of pay.

15. An extra motor coach operator working a regular run shall receive the same pay time, including overtime, that the regular assigned motor coach operator of such run would have received.

16. Extra board motor coach operators required to report for duty to protect the board, shall be paid until released or given a work assignment. If the extra man receives no other work assignment during the day in which he performs the protecting assignment or assignments, he shall receive not less than two and one-half ($2\frac{1}{2}$) hours pay time at his regular straight time hourly rate of pay for each assignment.

17 In the event an operator performs a protecting assignment, and in addition thereto performs other work, he shall be paid for such protecting time at his regular straight time hourly rate of pay, within

a minimum of two and one-half ($2\frac{1}{2}$) hours pay time, and without including such protecting time in the computation of overtime, if any, for that work day.

18. Regular motor coach operators shall be paid at the rate of one and one-half ($1\frac{1}{2}$) times their straight time hourly rate of pay for all work they are required to perform in any one (1) day in excess of their regularly scheduled run, or eight (8) hours and forty (40) minutes, whichever is the lesser.

19. All motor coach operators who are assigned to extra work on their days off shall receive a minimum of two and one-half ($2\frac{1}{2}$) hours pay at the overtime rates.

20. All regular motor coach operators who work extra runs, trippers, charters, specials, etc., in addition to their regular run shall be paid a minimum of two and one-half ($2\frac{1}{2}$) hours or overtime whichever is the greater.

21. No time shall be paid for a rate greater than one and one-half ($1\frac{1}{2}$) times the straight time hourly rate of pay.

APPENDIX C

THE USAGE OF THE DIGITAL COMPUTER FOR DETERMINATION OF PASSENGER LOAD AND VEHICLE REQUIREMENTS AND ESTABLISHMENT OF HEADWAYS

Previous research has been done in these two areas of scheduling. One of the earliest efforts in this field is the research done by the Philadelphia Transportation Company with the cooperation of I.B.M. (International Business Machines Corporation). For many years Philadelphia Transportation Company has recognized the need for increased flexibility in schedule preparation in order to more rapidly meet changing service requirements. In addition, Philadelphia Transportation Company wanted to prepare the best possible schedule with a minimum preparation cost. In order to accomplish these objectives, Philadelphia Transportation Company began seriously investigation the feasibility of automated transit scheduling. After some study, an automatic computer scheduling system was developed and has now been integrated into the operations.

Transit companies operate in the face of changing conditions and changing passenger needs. In addition to the unexpected changes, a given route must be prepared for:

1. Normal working hours
2. Morning and evening rush hours
3. School days
4. Holidays
5. Shopping nights

In order to meet these conditions, schedules must be constantly revised. However, manual methods, which are used throughout most of the transit industry have failed to provide:

1. Optimum scheduling at minimum costs, and
2. Flexibility in meeting changing service requirements.

Because of the inability of most companies to economically perform the vast amount of detailed work required within the limited time available, a complete schedule change is only effected after a prolonged period of time. Schedule changes deserving immediate action, such as shopping hours being extended a certain night, cannot be instituted, by manual methods in a short period of time.

Philadelphia Transportation Company has proven that by using I.B.M. 650, it is possible in the limited time between any schedule change to produce more schedules at less cost per schedule, and to make the following possible:

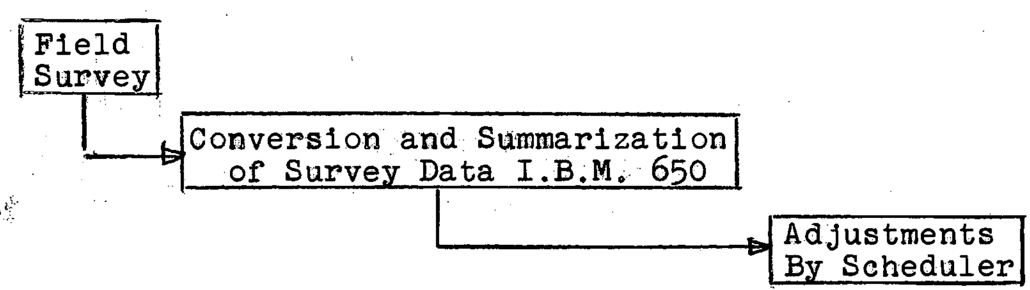
1. Rewriting of all schedules requiring change when necessary.
2. Considerable savings in time when making a schedule change. This means substantial dollar savings

because the service on a route may be altered to meet actual requirements at an earlier date.

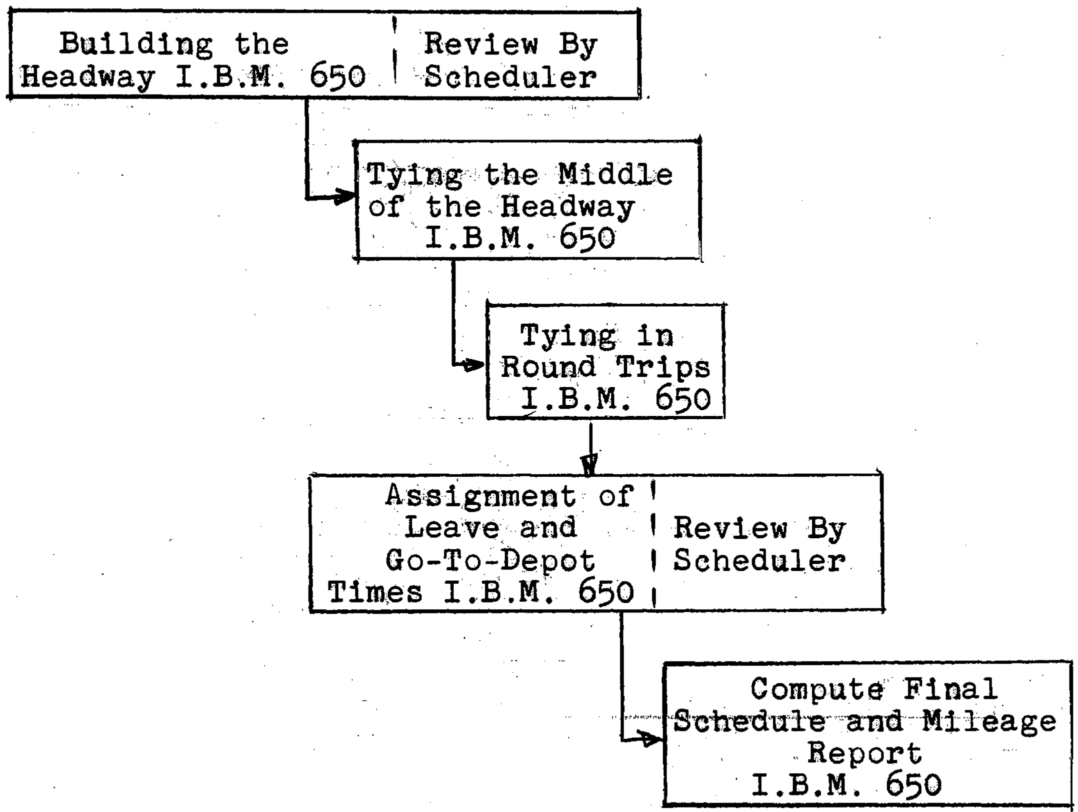
3. Direct and assured posting accuracy through the use of the I.B.M 407 Accounting Machine.
4. Reduction of clerical work and dollar savings.
5. Estimating of costs involving re-routing, extending, or consolidation of routes can be accomplished with greater speed and economy.
6. Peak loads for schedule changes are greatly reduced.
7. Clerical drudgery taken out of scheduling permitting the scheduler more time to devote to creative thinking and planning.

The procedure used by the Philadelphia Transportation Company to prepare schedules is organized into two phases. Phase I consists of three processing steps and Phase II consists of five processing steps. Each schedule under construction is processed in this manner.

Phase I



Phase II



A complete explanation of the system maybe obtained from the I.B.M. Library, "Transit Scheduling on the I.B.M. 650 at Philadelphia Transportation Company," (A general information manual).

APPENDIX D

SPACING OF BUSES ON A ROUTE

OR

HEADWAYS

The ideal situation is an equal spacing of buses on each route. In general, this is difficult to achieve because most routes have branches attached to them, each branch requiring a different number of buses. An acceptable compromise solution is usually obtained and requires a considerable length of time and experience on the part of the scheduler.

In an article published in Management Science,[1] the authors developed an equation to find an efficient schedule.

A bus schedule is called efficient if it minimizes the amount of man hours spent in waiting per hour by the passengers throughout the network.

In developing this equation the variation of the number of waiting passengers with time has been considered. However, the rate of passengers arriving at a certain stop was considered to be constant. This assumption is believed

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[1] J. W. Foulkes, W. Prager, and W. H. Warner, "On Bus Schedules," Management Science, I, p. 41.

to be realistic as long as the intervals between successive buses are sufficiently small.

This equation is associated with each branch in a route, resulting in a set of simultaneous equations. If the number of simultaneous equations exceeds three, it will be more desirable the usage of the digital computer for their solution. Several programs for simultaneous equations' solutions are already developed. It is suggested the use of the one developed by J. H. Schenck.[2]

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[2] J. H. Schenck, Simultaneous Equations Solutions, 650 Program Library File Number 5.2.019 (International Business Machines Corporation).

VITA

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Candidate for the Degree of

Doctor of Philosophy

Thesis: A DIGITAL COMPUTER SOLUTION TO THE TRANSIT OPERATOR ASSIGNMENT PROBLEM

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