A SIMULATION STUDY OF THE UNIVERSITY OF IOWA CAMPUS BUS SYSTEM

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ABSTRACT

A GPSS/360 simulation model of the University of Iowa campus bus system is given. The simulation model was constructed to study modifications of the current system necessitated by the rapid growth in ridership during the first year of service. The main GPSS model is based on three macros: a customer generation and destination macro, a bus macro, and a scheduling macro. Some recommendations concerning future operations are given.

1. INTRODUCTION

The University of Iowa's bus system, CAMBUS, was initiated in January of 1972. Its primary function is to provide intra-campus mobility for the university community, thus assisting with the development of a pedestrian campus and the reduction of vehicular-pedestrian congestion. The impact of the system has been significant. Traffic congestion has been reduced on campus as well as in the adjacent central business district.

Early success in the CAMBUS operation resulted in an expansion in services which, in turn, resulted in even higher ridership levels. Presently, buses are frequently filled to capacity and patron congestion is causing delays in schedules. Since experimental changes in schedules and routes aimed at alleviating these problems would be confusing to the patronage, a simulation model was constructed to study alternatives. The GPSS/360 language was selected because of its simplicity and its amenability to queueing problems.

2. THE SYSTEM AND ITS REQUIREMENTS

The University of Iowa campus is divided into two parts by the Iowa River. The medical complex, recreational and fine arts facilities, the fieldhouse and football stadium, and a complex of dormitories are located on the west side of campus. Most of the classroom facilities, faculty offices, and a dormitory complex are located on the east side of campus directly adjacent to the central business district.

The CAMBUS system is composed of three separate routes. The three routes, blue, red, and green (or express), and their respective paths of travel are exhibited in Figure 1. All bus stops have been assigned a bus stop number. The path of travel by bus stop numbers for each of the routes is given in Table 1.

The blue and red routes encompass nearly all areas of campus activity and travel in opposite directions. Each of these routes is allotted four buses. The buses, each with capacity of 70 passengers, travel their respective routes at 7-minute intervals. A period of 28 minutes for a completion of a route cycle allows the buses ample time to maintain schedule, except when patronage reaches capacity.

The green route is served by one bus. This bus, designated as the "express," travels back and forth between the two highest activity areas on respective sides of the campus. A cycle of the green route requires 14 minutes. Its path is a subset of the combined red and blue route, and thus, it competes or interacts for passengers with buses

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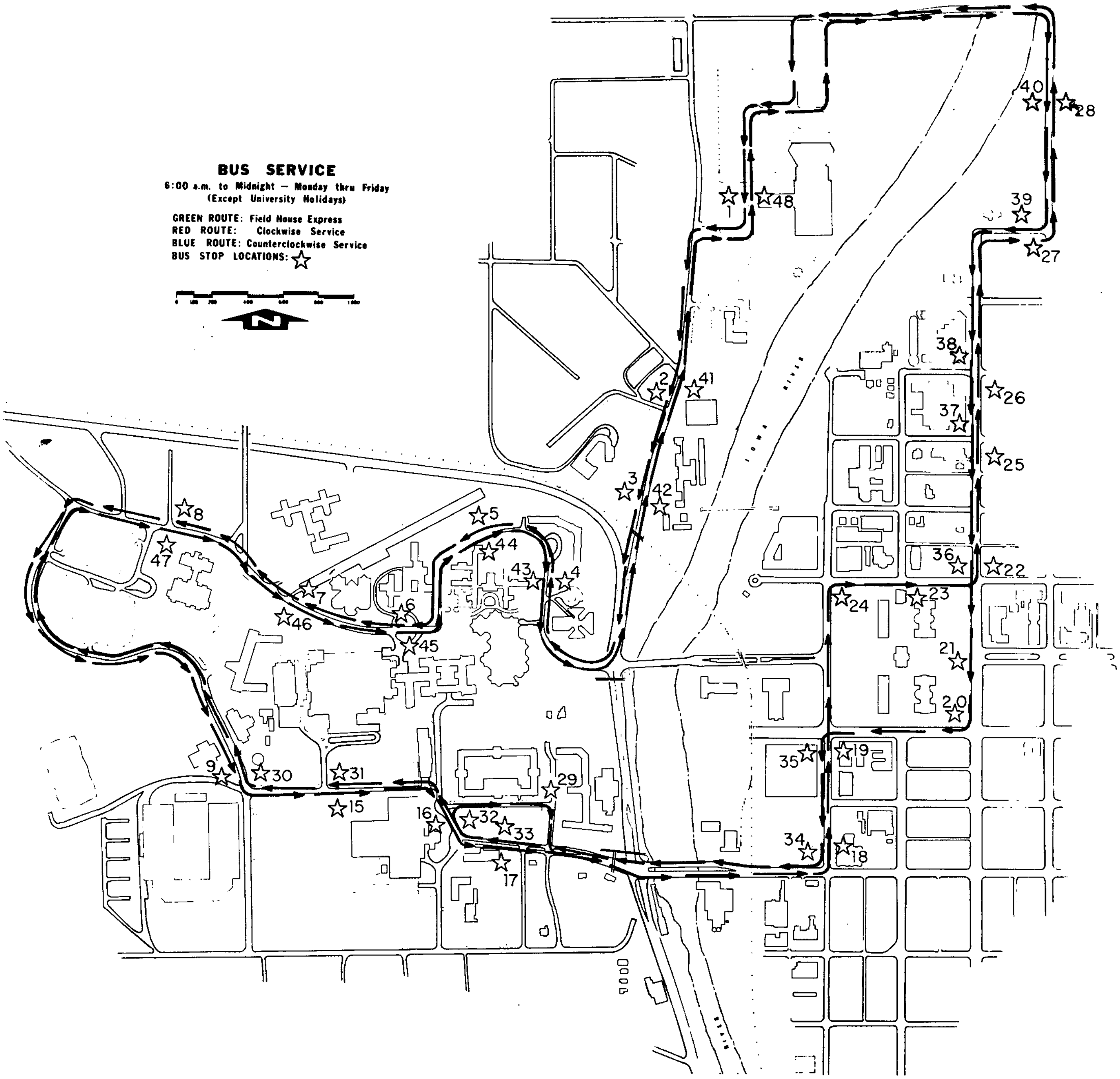


Figure 1. Campus Map

Table 1

Route Paths by Bus Stop Numbers

BLUE	1	2	3	4	5	6	7	8	9	15	16	17	18	19	24	23	22	25	26	27	28	1
RED	48	40	39	38	37	36	21	20	35	34	33	32	31	30	47	46	45	44	43	42	41	48
GREEN	20	35	34	29	16	17	18	19	24	23	21	20										

on these routes. A preliminary study indicated that the effect of this competition was negligible and hence it was ignored in the model.

The major portion of this study concerns the CAMBUS system during its peak hours of operation (11:00 a.m. to 1:00 p.m.). Although the basic simulation model is valid for any time period, the interarrival times and destinations of the patrons are highly dependent upon the time of day. In particular, the interarrival times and destinations in the early morning and late afternoon periods differ substantially from those used in this study.

The following information is required for an hour of simulation:

1. Bus schedules
2. Routes
3. Bus stop locations
4. Number of buses per route
5. Capacity level of each bus
6. Patron arrival rates at each bus stop corresponding to the hour that is to be simulated
7. Patron destination distributions for each bus stop corresponding to the hour that is to be simulated
8. Current between-stop headway patterns including bus-stoppage times for maintaining schedules and bus delay times when the bus is behind schedule.

Requirements 1 through 5 were obtained from the CAMBUS office. The last three requirements were estimated from an on-board sample survey.

3. FORMULATION OF THE MODEL

Before proceeding with the CAMBUS simulation model, the process is illustrated with a simple model which contains the basic components of the larger, more complex model. The simple model consists of one bus, one route, and four bus stops. Arrivals of customers to the system are generated deterministically at each of the bus stops. Their respective destinations are determined in a probabilistic fashion. Table 2 gives the specific attributes of the patrons being created at each of the four bus stops. The between-stop headways of the bus are given in Table 3. These time durations are constants in the simple model and take into account both travel time and boarding-and-debarking time.

The block diagram representing the bus as it travels through its route appears in Figure 2. The block diagram representing the activity which takes place at each bus stop appears in Figure 3. Similarly, Table 4 defines the action of each block that appears in Figure 2; Table 5 defines the action of each block that appears in Figure 3. Statistics are collected on waiting times of prospective passengers at each bus stop, which is represented by a user chain in the program. Statistics are also collected for each bus, which is represented by a storage in the progam. Storage statistics include the average time spent by the passengers on the bus, and the number of transactions (people on bus) that have passed through each block.

Table 2

Simple Model: Patron Attributes

Bus Stop Origin	Time Between Patron Arrivals	Bus Stop Destination (%) 1	2	3	4
1	20	--	60	30	10
2	10	40	--	50	10
3	60	30	60	--	10
4	120	40	40	20	--

Table 3

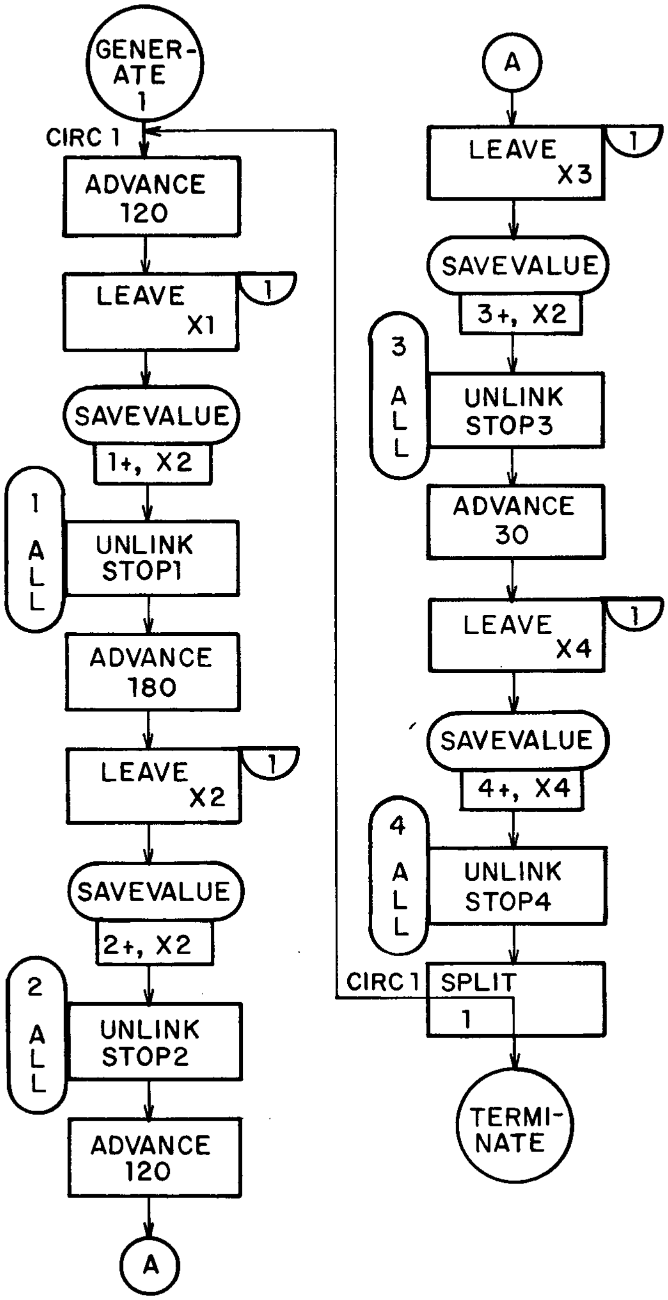
Simple Model: Between-Stop Headways of the Bus

From	To	Time (secs)
1	2	180
2	3	120
3	4	30
4	1	120

In formulating the CAMBUS model, additions and modifications to the simple model are necessary. One of these modifications involves the method by which buses attempt to maintain schedules. On each route of the system, there are check points. If the bus is ahead of schedule at these points, it must wait the amount of time it is ahead before proceeding. In order to accommodate the system's scheduling procedure, a series of blocks are inserted at each of the bus stops where schedules are to be checked against the clock.

Another addition to the simple model is the bus delay factor. The purpose of the bus delay factor is to vary the time duration between bus stops according to the bus's current passenger load. Thus, the current level of usage of a bus is assumed to be an indication of delay caused by boarding and debarking of its passengers. The bus delay factor is multiplied by the normal between-stop headway. The delay function used by the model was selected through study of the effects of several different possible delay functions on the model and subsequent calibration.

Further modifications to the simple model include arrival rates and destination functions which change during the hour in order to accurately depict fluctuation that occurs in the actual system.



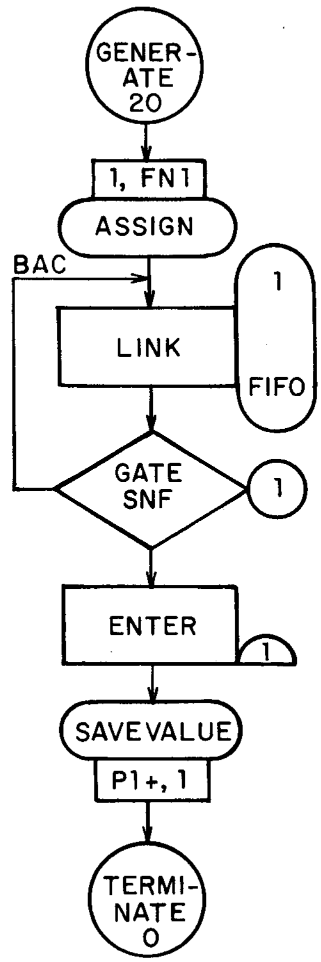


Figure 3. Simple Model: Bus Stop Activity

Figure 2. Simple Model: Bus Activity Through the Route

Preliminary analysis of the data indicated that the buses were encountering a relatively small amount of bus utilization in the northwest area of the campus (Hancher Auditorium-Recreation Center) as compared to utilization in the remainder of the campus. Based on this conclusion, an alternative system consisting of two routes was proposed. The "east" route begins at Hancher Auditorium (Stops 1 and 48), follows the existing red route bus stops on the east side of campus and proceeds to the Recreation Center (Stops 9 and 30) on the west side of campus. At that stop, the route reverses and proceeds back through the existing blue route stops to Hancher Auditorium (Stops 1 and 48) where the cycle begins again. This route is serviced by seven buses. The "west" route proceeds from Hancher Auditorium (Stops 1 and 48) to the Recreation Center (Stops 9 and 30) via the existing blue route and back to Hancher Auditorium (Stops 1 and 48) via the existing red route. It is the complement of the former and is serviced by two buses.

Two additional modifications to the model are required to accommodate the alternative system. The first modification is the method by which the model deals with patrons at the terminals of the route (Hancher Auditorium and the Recreation Center).

Table 4

Simple Model: Explanation of Bus Activity Through the Route

Block	Description
GENERATE	The bus is created at the beginning of the run.
ADVANCE	The bus proceeds from stop 4 to stop 1.
LEAVE	Passengers with stop 1 destination leave the bus.
SAVEVALUE	Savevalue 1 contains the number of passengers whose destination is stop 1. Its value can now be set to zero.
UNLINK	Prospective passengers waiting at stop 1 are "unlinked" and board the bus.
	The ADVANCE-LEAVE-SAVEVALUE-UNLINK sequence is repeated for bus stops 2, 3, and 4 and is followed by:
SPLIT	The bus is placed at the beginning of its route again.

Table 5

Simple Model: Explanation of Bus Stop Activity

Block	Description
GENERATE	Patrons arrive at the bus stop to await the bus.
ASSIGN	Each patron is probabilistically assigned a destination.
LINK	The patron joins a FIFO waiting line.
GATE SNF	Patrons await arrival of bus.
ENTER	Patrons board the bus until it reaches capacity. If it reaches capacity the remaining customers wait for the next bus.
SAVEVALUE	The destination counters are updated.
TERMINATE	Patrons board the bus.

Passengers whose destinations were not at the terminal and who remain on the bus when it reaches a terminal must debark the bus and join the bus stop queue which waits for a bus servicing the complementary route. The series of blocks which accomplishes this task is shown in Figure 4. A block-by-block explanation of series is given by Table 6.

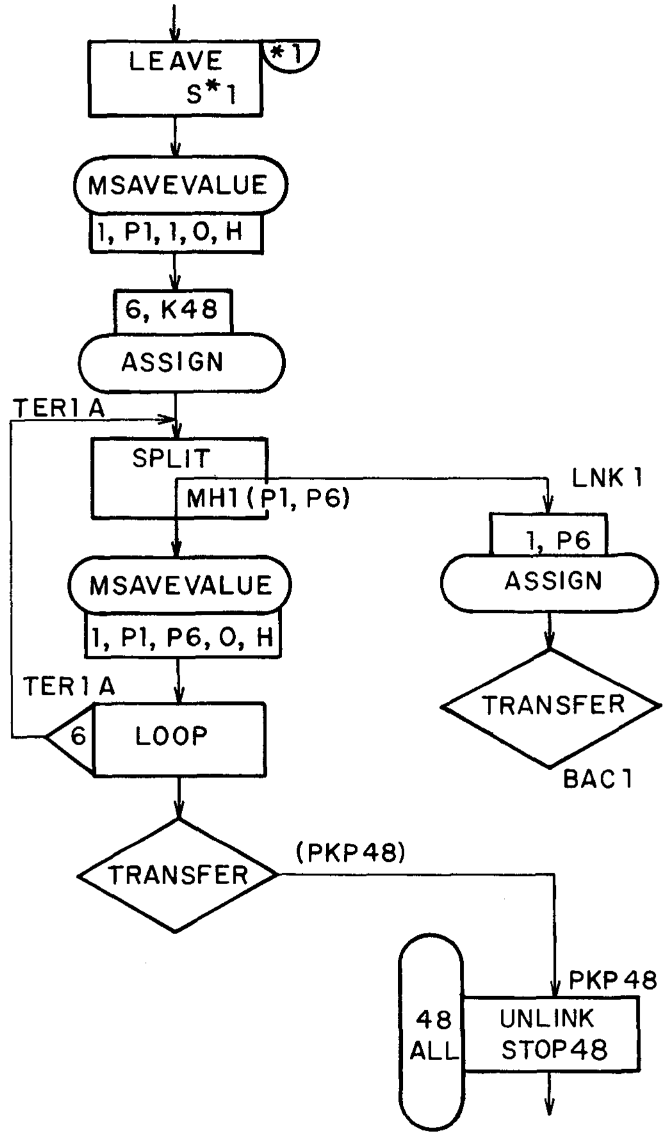


Figure 4. Bus and Passenger Activity at Route Terminals

The second modification to the model merges the express route patron arrivals with the blue and red route patron arrivals. Thus, two or three sets of arrivals are generated simultaneously at each of several bus stops.

Since many of the activities of the bus system are repetitious, the main program can be simplified using GPSS MACRO statements. The three primary macros used in the model, entitled BUS, BSTOP, and TABIT, are given in Figure 5.

Table 6

Explanation of Bus and Passenger Activity at Route Terminals

LEAVE	The bus has just arrived at a terminal of the route. All passengers debark the bus (whose number is stored in parameter 1) since their destinations had either been at the terminal or at a point beyond the terminal.
MSAVEVALUE	The number of passengers whose destination had been the terminal is subtracted from the stored contents of the bus.
ASSIGN	A looping parameter is assigned a value of 48. The loop will retransform passengers (whose destinations are beyond the terminal) back into transactions according to their destinations.
SPLIT	The matrix savevalue contains the number of passengers wishing to go to each bus stop destination (in this case, beyond the terminal). Thus, patrons are recreated by destinations and sent to block LNK1.
MSAVEVALUE	The number of passengers whose destination had been the current looping value is subtracted from the stored contents of the bus.
LOOP	The looping value (also the destination value) stored in parameter 6, is decremented by one and the bus transaction is sent back to the top of the loop, TER1A.
TRANSFER	After the completion of the loop activity, the bus transaction is sent to block PKP48 to turn around and pick up patrons waiting at bus stop 48 to go to destinations on the route from which the bus has just come.
ASSIGN	The destination of transfer passengers is placed in parameter 1.
TRANSFER	Transfer passengers are sent to bus stop 1 to wait for a bus arrival from the other route.
UNLINK	The bus which has just arrived at the terminal and unloaded its passengers now picks up patrons waiting at bus stop 48 to go to destinations on the route from which the bus had just come.

The purpose of macro BUS is to move the bus from its current bus stop to the next bus stop along the route, to unload passengers whose destination is that bus stop, and to allow passengers at that bus stop to board the bus. Four parameter values are required each time this macro is called. Parameter #A is the time allotted (under normal conditions) for the bus to get from its current bus stop to the next bus stop. Parameter #B is the matrix location which contains the number of passengers whose destination is the bus stop at which the bus arrives. The matrix location is referred to as MH1(P1,x), where x is the number of that bus stop. Parameter #C is the number of the bus stop and parameter #D is the program address of the bus stop, STPx, where x is the bus stop number.

The purpose of macro BSTOP is to generate arrivals of patrons at a particular bus stop, to determine (or assign) their respective destinations and to load them on a bus as it arrives at the bus stop. Five parameter values are required for this macro. Parameter #A refers to the value location of the set of destination functions applicable to the bus stop. The value #A must be equal to one less than the number of the first of four consecutively numbered destination functions of the appropriate bus

```
BUS     STARTMACRO
        SAVEVALUE     50,#A,H
        ADVANCE       V23
        SAVEVALUE     47,#C,H
        SAVEVALUE     V49,P1,H
        LEAVE         *1,#B
        MSAVEVALUE    1,P1,#C,0,H
        UNLINK        #C,#D,ALL
        ENDMACRO

BSTOP   STARTMACRO
        ASSIGN        3,#A
        ASSIGN        3+,FN107
        ASSIGN        1,FN*3
#C      LINK          #B,FIFO
#D      GATE SNF      #E,#C
        ENTER         #E
        MSAVEVALUE    1+,#E,P1,1,H
        ENDMACRO

TABIT   STARTMACRO
        SAVEVALUE     46,#A,H
        SAVEVALUE     48,MPS,H
        TEST G        XH48,XH46,#B
        TABULATE      #E
        ASSIGN        7,V25
        TRANSFER      ,#C
#B      TABULATE      #D
        ADVANCE       V24
#C      UNLINK        #F,#G,ALL
        ENDMACRO
```

Figure 5

The Model's Three Primary Macros

stop. Parameter #B is the bus stop's number. Parameters #C and #D are names of particular block statements. Specifically, parameter #C contains the name BAKx and parameter #D contains the name STPx, where x is the number of the bus stop. Parameter #E is the name of the savevalue whose number is 50 plus the value of the bus stop number.

The macro TABIT is used at schedule-check points and holds the bus when it is ahead of schedule. Also, tabulations are kept of the amount of time the bus is ahead of or behind schedule. TABIT requires seven parameter values. Parameter #A is the amount of time since the beginning of the route cycle that should have passed before the bus's departure from the bus stop. Parameters #B and #C are names of statements used within the macro. They are, respectively, TABx and XGOx where the value of x is arbitrarily chosen to be the number of the table or the number of the TABIT macro. Parameters #D and #F are the numbers of the tables which will contain the schedule tabulations. Parameter #G is the bus stop number. Parameter #H is the address name of the bus stop, or STPx, where x is the bus stop number.

The operation of a bus through a route can now be viewed as a series of MACRO statements preceded by a GENERATE block and followed by a SPLIT block. The GENERATE block initializes a bus; the SPLIT block sends the bus back to the beginning of the route. Figure 6 illustrates a bus's operation through a hypothetical three-stop route. Macro BUS* is a slight modification of macro BUS which labels the first bus stop location with the name of the route (in this case, XAMPL) so that the bus can be moved back to the beginning of the route after a cycle has been completed. The name of the route (XAMPL) is placed in parameter #E of macro BUS*. Note that the example also illustrates the use of macro TABIT, such that bus stop #2 becomes a schedule-check point.

```
        GENERATE
BUS*    MACRO      60,MH1(1,1),1,STP1,XAMPL
BUS     MACRO      60,MH1(1,2),2,STP2
TABIT   MACRO      120, TAB1,XG02,1,2,2,STP2
BUS     MACRO      60,MH1(1,3),3,STP3
        SPLIT      1,XAMPL
        TERMINATE  0
```

Figure 6

Example of Bus Movement Through a Hypothetical Route

Similarly, the action of patrons at a hypothetical bus stop is illustrated in Figure 7. In this example, arrivals occur exponentially with a mean arrival rate of 10 seconds.

```
        GENERATE   10,FN$EXPO
BSTOP   MACRO      7,3,BAK3,STP3,XH53
        TERMINATE  0
```

Figure 7

Example of Action Occurring at a Hypothetical Bus Stop

4. Comparison of Systems

The existing system and three variations of the alternative system were evaluated using the model. The variations have differing time intervals between buses and surplus waiting time designated at certain bus stops. The first variation of the alternative system, Plan A, allows six-minute intervals between buses on the east route with a complete cycle of the route requiring 42 minutes. The west route constitutes ten-minute intervals between buses with a complete cycle of the route requiring 20 minutes. The east route of Plan B consists of 5 five-minute intervals and 2 six-minute intervals between buses with a route cycle of 37 minutes. The west route of Plan B is identical to that of Plan A. The east route of Plan C consists of 6 five-minute intervals and 1 six-minute interval between buses with a route cycle of 36 minutes. The west route of Plan C constitutes nine-minute intervals between buses and a route cycle of 18 minutes. Slack time for each of the plans, including the existing CAMBUS system, is assigned to bus stops according to the designations given in Table 7. In each cell of the table, the number represents the amount of time (in seconds) buses are scheduled to wait at the respective bus stops.

The three most important factors weighing upon the comparison of the systems are the average amount of waiting time by all patrons at the bus stop, the average amount of time spent on the buses by all passengers, and the ability of the buses to maintain schedules. Since, in the alternative plans, some passengers must transfer buses in order to reach their destinations, they must also wait twice and ride two different buses. These considerations are made in calculations of average waiting times and average transit times.

Table 8 contains a summary of the performance in the model of the existing system and the three alternative plans. The existing system and the system of Plan C were each tested with two different random number sequences. The time spent by patrons in the system is significantly less in Plan C as compared to the existing system. Though the time spent on buses is approximately the same for the two systems, the average time spent by all patrons at their initial boarding points is, on the average, 43 seconds less in Plan C's system than in the existing system. One deficiency of Plan C is the fact that nearly 20% of the patrons must transfer buses, since they are either coming from or going to a point within the low usage area. Yet, even when the second boarding wait time of these patrons is figured into the waiting averages, an average of 14 seconds is saved over the existing system. Another advantage of Plan C is that it allows for greater flexibility in scheduling and routing. Modification of Plan C such as overlapping the east and west routes could conceivably eliminate a good portion of the percentage of patrons requiring bus transfers.

The ability of the buses to maintain schedules is considered in Table 9. The calculations are derived directly from tables of the output. The table indicates that while the buses of Plans B and C fall behind schedule approximately 40-50 seconds in a section of the east route, slack waiting time allows the buses ample time to catch up with their schedules.

The model formulated in this paper is capable of evaluating new CAMBUS routes made necessary by changes in campus facilities, such as the addition of peripheral parking lots. Continuing success of the CAMBUS system will depend even more heavily upon efficient routing and scheduling in the future because of increased gas prices and budgetary limitations.

Table 7

Time Intervals Between Buses, Route Cycle Durations, and Scheduled Bus Waiting Times

		EXISTING PLAN	PLAN A	PLAN B	PLAN C
Time intervals between buses		7 min	East 6 min West 10 min	East Five 5-min, Two 6-min West 10 min	East Six 5-min, One 6-min West 9 min
Cycle duration in minutes		28	East-42 West-20	East-37 West-20	East-36 West-18
BUS STOP	1	B-180	W-170	W-170	W-50
	9	-----	E-180	E-120	E-90
	20	R-60 G-60	E-120	-----	----
	23	B-60	E-90	-----	----
	30	-----	W-75	W-75	W-75
	48	R-180	E-180	E-150	E-120

Blue (B), Green (G), Red (R), East (E), West (W)

Table 8

Summary of Performance of the Existing System and Alternative Plans

	EXISTING PLAN Run 1	EXISTING PLAN Run 2	PLAN A	PLAN B	PLAN C Run 1	PLAN C Run 2
Total # of patrons at all bus stops	1472	1401	1485	1532	1510	1434
Average waiting time (sec) for all patrons at initial bus stops	207.0	211.1	181.0	179.6	169.4	164.4
Total # of transfer passengers	-----	-----	315	312	307	328
Average waiting time (sec) for transfer passengers at 2nd bus stop	-----	-----	94.7	160.9	135.7	128.4
Average waiting time (sec) for all patrons at bus stops	207.0	211.1	201.1	212.4	197.2	193.8
Total # of bus passengers	1529	1483	1610	1600	1613	1543
Average time (sec) on buses for all passengers	378.1	394.6	417.2	387.2	377.8	375.5
Average total time (sec) in system including all bus stop waits	585.1	605.7	618.3	599.6	575.1	569.3

Table 9

Bus Progress in Maintaining Schedule by Average Number of Seconds Ahead of Schedule

EXISTING SYSTEM				PLAN A			PLAN B		PLAN C		
Schedule Check Bus Stop	Scheduled Wait	Model Run 1	Model Run 2	Schedule Check Bus Stop	Scheduled Wait	Model	Scheduled Wait	Model	Scheduled Wait	Model Run 1	Model Run 2
6	0	18.7	15.6	38	0	-15.2	0	-7.5	0	-10.8	-7.8
10	0	8.1	9.7	20	0	84.4	0	-12.3	0	-12.6	-5.0
14	0	-16.8	-13.7	9	180	156.8	120	70.7	90	46.8	54.6
16	0	26.3	27.5	19	0	-14.4	0	-32.0	0	-26.5	-18.4
19	0	-4.4	-4.4	23	0	90.6	0	-52.0	0	-47.4	-36.0
1	180	172.6	171.5	48	180	179.8	150	102.0	120	79.5	91.5
38	0	13.9	13.8	6	0	10.8	0	10.8	0	11.7	13.5
20	60	43.7	38.6	30	75	72.8	75	72.0	75	75.0	76.1
31	.0	-14.9	-24.6	45	0	18.0	0	17.3	0	18.3	15.7
46	0	0.0	-9.9	1	170	169.7	170	170.0	50	52.1	50.1
48	180	170.3	160.6								
20	60	78.6	88.0								
29	0	11.5	11.0								

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