BLAST
(Bus LAne Simulation Tool)

3123

DESCRIPTION

BLAST is an abridged version of SIBULA (Lindau, 1983) incorporating all features relevant to simulating bus operation. Runs on IBM PC compatible machines under the Microsoft's Fortran 77 environment. Capable of simulating the operation of buses along exclusive high-flow median priority lanes on a microscopic level of detail. Useful for testing combinations of alternative geometric and operational conditions under identical traffic input settings.

COMPONENTS OF THE MODEL

BLAST is formed by two main processors. A pre-simulation processor is used to define the bus traffic stream. Units are generated based on traffic parameters and the results stored in arrays for subsequent use. Other functions of the pre-simulation processor include obtaining, processing and storing all the geometric and traffic details that are held constant throughout the simulation run. Most calculations involve the generation of random variables of defined probability distribution functions.

The traffic simulation processor carries out the repetitious computations required for simulating the movement of each bus at every time increment. It also caters for the insertion and removal of buses.

OVERALL STRUCTURE OF THE MODEL

Each bus entering the system is uniquely identified in terms of its performance characteristics. These characteristics are randomly drawn from specific distributions and influence the selection of reactions such as free-flow acceleration and deceleration. Vehicle-following routines are used to update constrained buses. Such procedures enable BLAST to generate microscopic bus trajectories sensitive to changes in the traffic signal control policy, alterations in the bus boarding conditions and impedance caused by other buses. As buses approach intersections, they may either proceed through or stop, according to the traffic signal display and an amber reaction procedure. Buses are generated according to pre-specified flows and are processed along the system stopping at their assigned stations. Individual dwell times are based on the number of passengers boarding which, in turn, are related to previous bus arrivals. Provision is made for evaluating the effects of adopting different bus-stop configurations and simulating a variety of alternative high-flow bus operation techniques.

MAIN FEATURES

simulation time

Usually one hour, at a given bus flow rate.

road geometry

A single median bus lane, with up to 40 intersections and 40 traffic signals.

traffic signals

Common cycle, green, red and amber times for all intersections. Offset can be either input or calculated by the program - bandwidth method, 2 directions.

vehicle characteristics

Include: desired speeds, acceleration/deceleration, amber reaction, intervehicular stopping distances, length and width - average, standard deviation, maximum and minimum values to be input where appropriate. The model uses own random number, exponential and normal routines to generate vehicle characteristics.

bus operation

Buses can operate at the stops under different conditions. Boarding may occur in the vicinity of the stops, anywhere within the boundaries specified by the user. Alternatively, ordered convoys are assembled before bus insertion and vehicles are only allowed to load at specific bus bays. Bus overtaking may occur if a special lane is provided nearby the bus stop areas.

Total number of buses in a convoy can vary up to 10; by assigning letters to the different bus stop bays, several convoy combinations may be explored: A-B-C-D-E-F, A-A-B-B-C-C, A-A-A-B-B-B (a convoy of 6 buses divided in 2 groups) and so on.

Bus stop bay groups are selected via a probabilistic function that takes into account the previous assignments. Initial headways are determined by a shifted negative exponential function; input time will depend on conditions selected for insertion.

The user can select one amongst several options for vehicle insertion:

OPTION 0 - buses generated on a first in/first out basis at the retention line of first traffic signal. Insertion time takes into account the signal display. Buses travel on a non-ordered basis.

OPTION 1 - buses generated in ordered convoys which may or may not be completed (full) as vehicles are released when signal aspect of first intersection is green for bus insertion. If a full ordered convoy is waiting at the onset of green, it proceeds immediately; if not, the controller waits some time until just enough green time remains to release what could or not be a full

convoy. Buses travel on an ordered basis.
OPTION 2 - buses generated only when full convoys are assembled and signal aspect of first intersection is green for bus insertion. One or more convoys can be released during one green time. Buses travel on an ordered basis.

OPTION 3 - buses generated on a first in/first out basis. Insertion time is equal to initial headway. Buses travel on a non-ordered basis.

OPTION 4 - buses generated only when full convoys are assembled. Buses travel on an ordered basis. This provides identical results to option 5 running for long queues and long waiting times.

OPTION 5 - buses generated in ordered convoys which may or may not be completed (full) as vehicles are released either if the waiting queue of any bus stop group reaches a certain number or if a maximum waiting time since the release of the previous convoy has elapsed. Buses travel on an ordered basis.

Typically, the following options would be alternatively selected for controlling the insertion of buses:

a. along the main road:
(ordering signals operated automatically or by controller)
peak periods: OPT 5, 4
off peak: OPT 3

b. from a side road:
(green lights for buses depending on signal coordination of main road)
peak periods: OPT 1, 2
off peak: OPT 0

OUTPUT

As BLAST updates all vehicle kinematic characteristics at each time interval, a wide range of different output can be obtained. Amongst them:

a.display of input data - the standard output of the model includes a printed summary of the main geometric and flow parameters specified for each simulation run. A special printout, including the initial characteristics of all buses being simulated can also be produced on request.

b.measures of effectiveness - individual and average travel times and operational speeds. Alternatively, more detailed information such as queue lengths during red signals, output flows at different locations and delays at insertion due to convoy formation, can also be obtained.

c.plots - the model generates data to produce a graphical display of trajectories of buses against time. It helps the comparison of alternative bus strategies.

APPLICATION

The considerable degree of flexibility included in the formulation of BLAST enables the investigation of a wide range of geometric designs, traffic management and bus operation schemes along a high-flow median priority lane. Each of the cases to be studied will be specified by a combination of ~~the~~ the following elements:

a. lane width - median bus lane may consist of a single lane on either direction of flow or may be provided with an extra lane at the stops to allow express buses to overtake local ones.

b. bus stops - with variable locations in relation to signalised intersections (mid-block, near-side and far-side) and lengths (number of bays or buses that can be simultaneously attended).

c. bus convoys - different sizes and combinations of letter groupings/ bus bays. Initial delays to form convoys computed against benefits that may arise from running them.

d. traffic signals - variable cycle lengths, splits and offsets.

e. roadway geometry - variable lengths, location and frequency of bus stops and intersections.

L. A. Lindau
CPGEC/UFRGS
Caixa Postal 303, Ag. Central
Porto Alegre, RS
90001 - BRAZIL

11th October 88.

ANNEX 1

AN OVERVIEW OF SOME OF THE OUTPUT PRODUCED BY BLAST

PERFORMANCE OF INDIVIDUAL BUSES

An example of the capability of BLAST in representing the kinematic behaviour of different buses is indicated in the figure 1. Speed vs. time plots are useful as they enable a very detailed view of the bus progression and a good understanding of the vehicle-following procedure. In the example, seven successive buses travel under restricted conditions.

The leader enters the simulated section at a given desired speed; the others are generated with desired speed levels which are either above or below preceding vehicles, and in the former case must adjust by decelerating. The leader starts reducing its speed to stop by the traffic lights; soon after, the others begin similar manoeuvres dictated by the vehicle-following rules. Signal display turns to green and the leader starts accelerating again towards its desired speed. Finally all vehicles achieve the standstill condition at their respective bus stop bays.

JOURNEY TIMES

The overall journey time along the corridor is formed by initial delays arising from the setting of bus convoys plus the travel time along the priority lane.

Initial delays

Initial delays vary according to the alternative selected for the insertion of the buses. The set of results depicted in figure 2 indicates the distribution of initial delays due to traffic signals and to setting ordered convoys. They were produced by running BLAST under different insertion conditions (options 0, 1, 2, 4 and 5 as described before compared against option 3 - 'do-nothing'). The same set of random seeds was used as to guarantee the generation of identical sequences of buses.

The following conditions apply to the results (as indicated in the figures when appropriate):

cycle time = 60 seconds
green time for buses = 36 seconds
input flow = 300 buses per hour
minimum headway between successive buses = 3 seconds
maximum waiting queue = 5 buses
maximum headway between successive convoys = 30 seconds

Figure 3 shows insertion times arising from setting full convoys (option 4) against the do-nothing condition for a few convoys. A1,A2,B1,B2,C1,C2 is the insertion order and individual delays are represented along the y axis. As expected, the shortest delays are associated to those buses which arrive last, i.e., complete the convoys.

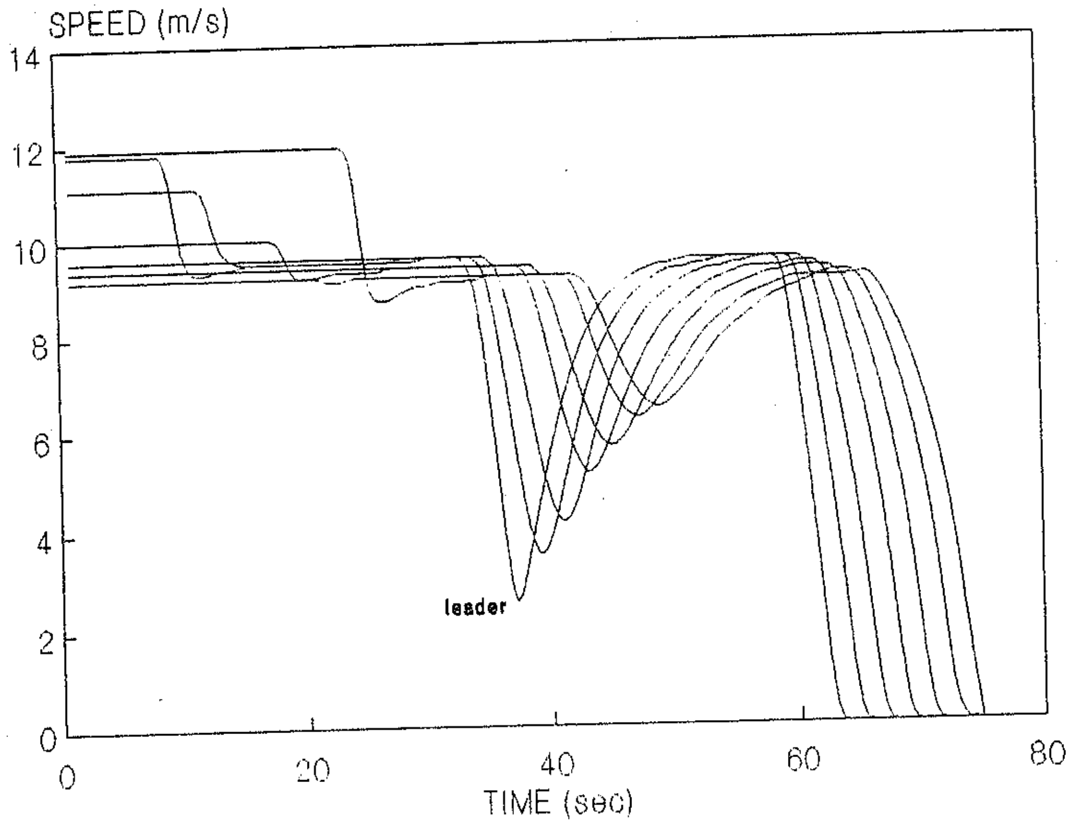
Travel time

Overall travel time results as a sum of the initial delay in forming convoys plus the travel time along the median bus lane. Figure 4 shows some of the final journey speeds produced by running BLAST for the conditions described in annex 3. Input flow is at the 300 buses/hour level and each dot represents average results for a group of buses leaving the simulated section over a period of 5 minutes. Over the first 5 minutes only a small number of buses leave the section and as the system was empty, higher speeds are achieved (it is normal procedure to eliminate initial periods from the analysis and the user of BLAST can select this alternative). As the output flow increases, average travel time tends to drop; but the variability of the results presented in figure 4 tends to indicate that the system is operating under its capacity level and that higher input bus flows could be accommodated.

Figure 5 depicts the results attained by increasing the flow to 498 buses/hour. Speeds keep decreasing with simulation time while output/input flow tends to 1, a strong indication that the system is reaching saturation. Bus speeds still compare favourable with fig 4 as now initial delays to form full convoys, shown in figure 6, are, on average, 22.9 seconds less than before (see fig. 2 for volume=300) and the section being simulated is short, only 1250 metres long.

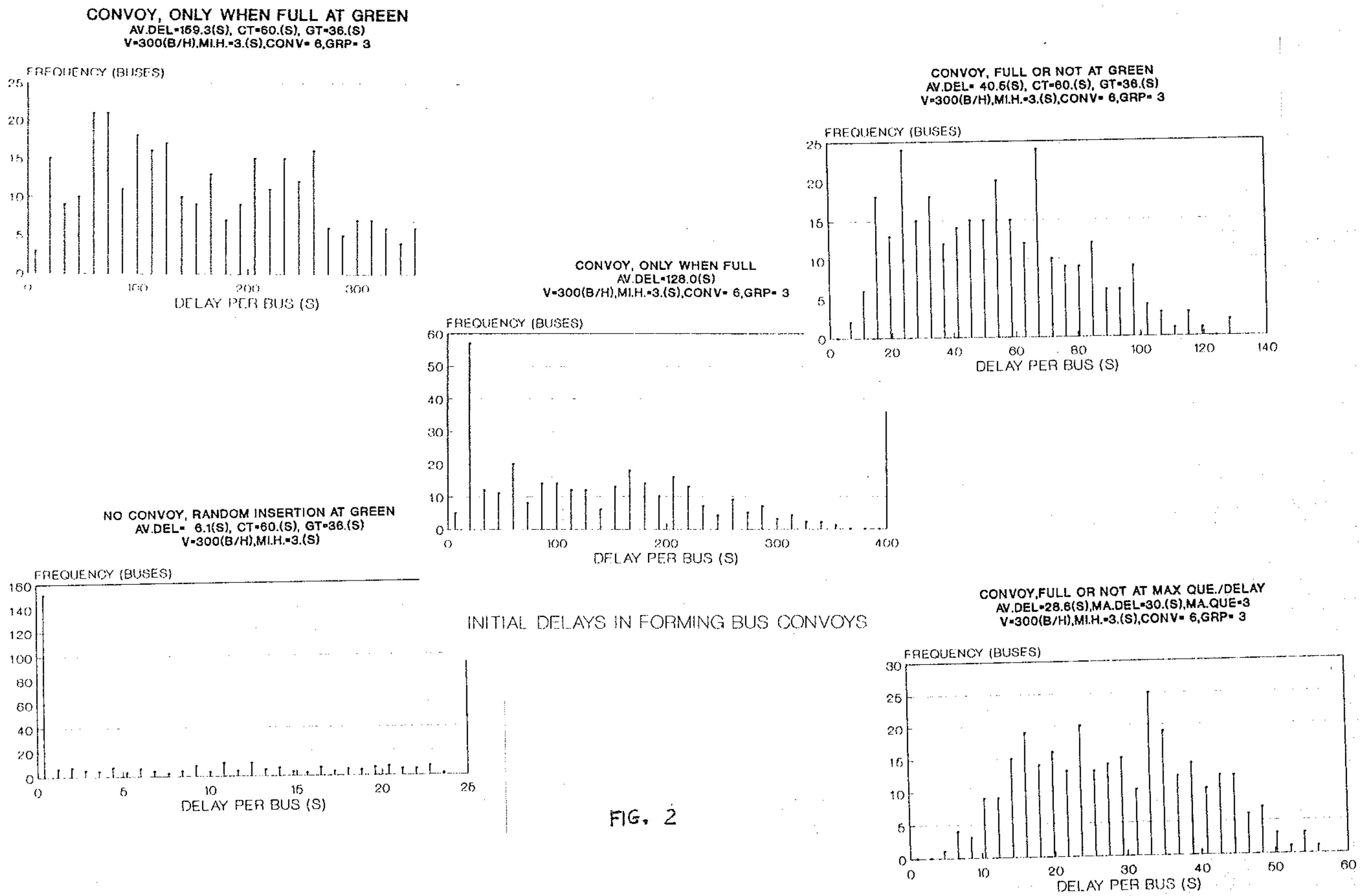
In figure 7 buses must stop over the pre-defined bus bays although no initial ordering is set for them, i.e. they are inserted as they arrive although they do have an assigned bus bay to stop. Buses can now be impeded to reach their bays while passengers board front vehicles (say, when the front bus belong to an B or C group and the follower is an A bus). Consequently speeds should be lower than the ones achieved by the same group of buses attending bus stations which are not divided in bays. In fact, figure 8 presents the results arising from operating buses without assigning letter groups; in this particular case, 4 buses can be simultaneously attended at the stops. Boarding times have been kept at the same level as the situation represented in figure 7, although it would be fair to increase them as passengers have now to search for their buses. For simplification, the boarding times have been kept constant for all buses throughout all the results produced here (see annex 3), i.e. in the input data IBCO was set as equal to 1. IBCO equal to 0 would be more representative of the real world and would probably lead to different results.

VEH-FOLLOWING (7 buses)
GSP= 10.5 GSPD= 1.4 RAC= .08
GSD= 1.2 GSDD= .3 CB= 10.7



describes the performance of 7 buses while adjusting to the speed of the leader, decelerating and stopping.

FIG. 1



INITIAL DELAYS IN FORMING BUS CONVOYS

FIG. 2

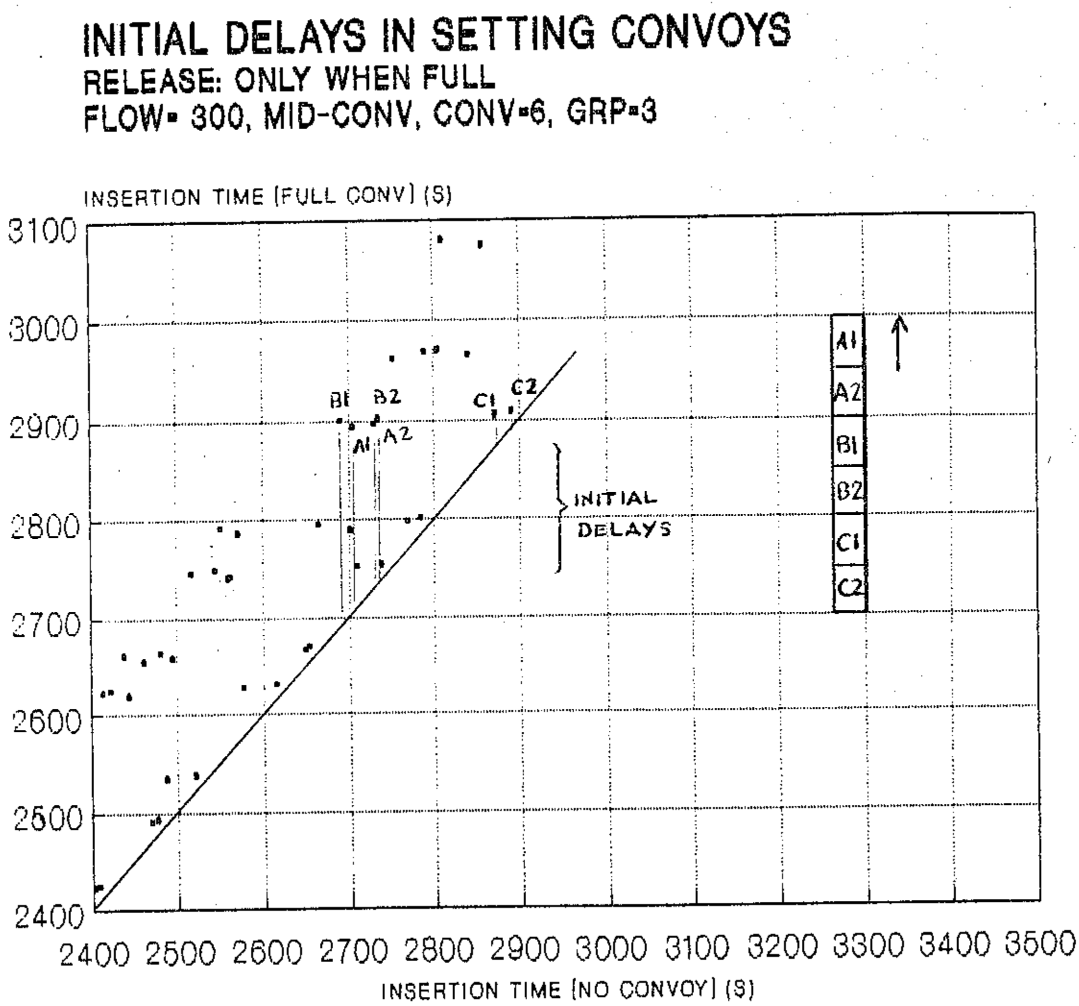
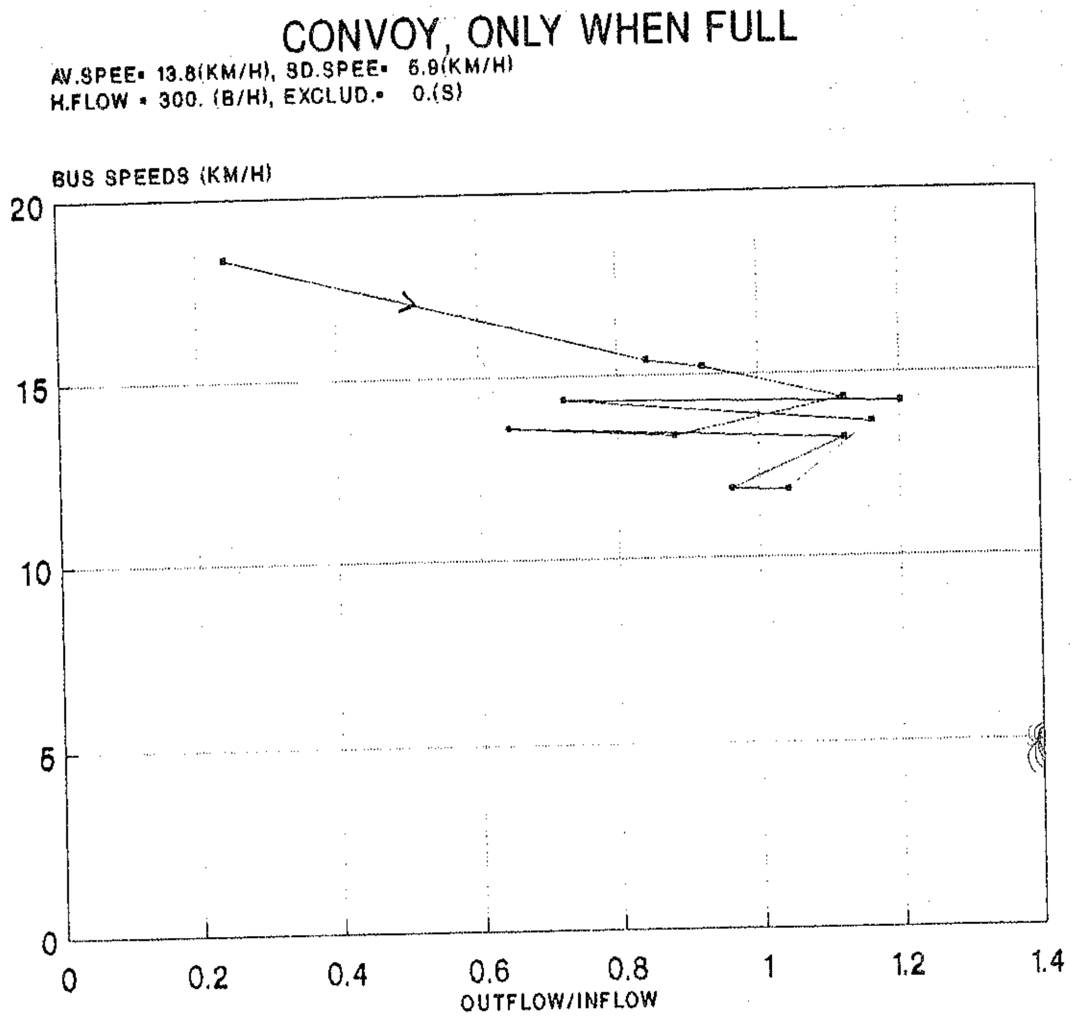

INITIAL DELAYS IN SETTING CONVOYS
RELEASE: ONLY WHEN FULL
FLOW= 300, MID-CONV, CONV=6, GRP=3
INSERTION TIME (FULL CONV) (S)
3100
3000
2900
2800
2700
2600
2500
2400
2400 2500 2600 2700 2800 2900 3000 3100 3200 3300 3400 3500
INSERTION TIME (NO CONVOY) (S)
B1
B2
A1
A2
C1
C2
INITIAL DELAYS
A1
A2
B1
B2
C1
C2

FIG. 3



CONVOY, ONLY WHEN FULL
AV.SPEE= 13.8(KM/H), SD.SPEE= 6.9(KM/H)
H.FLOW = 300. (B/H), EXCLUD.= 0.(S)
BUS SPEEDS (KM/H)
20
15
10
5
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
OUTFLOW/INFLOW

FIG. 4

CONVOY, ONLY WHEN FULL

AV.SPEE= 12.9(KM/H), SD.SPEE= 4.6(KM/H)
H.FLOW = 488. (B/H), EXCLUD.= 0.(8)

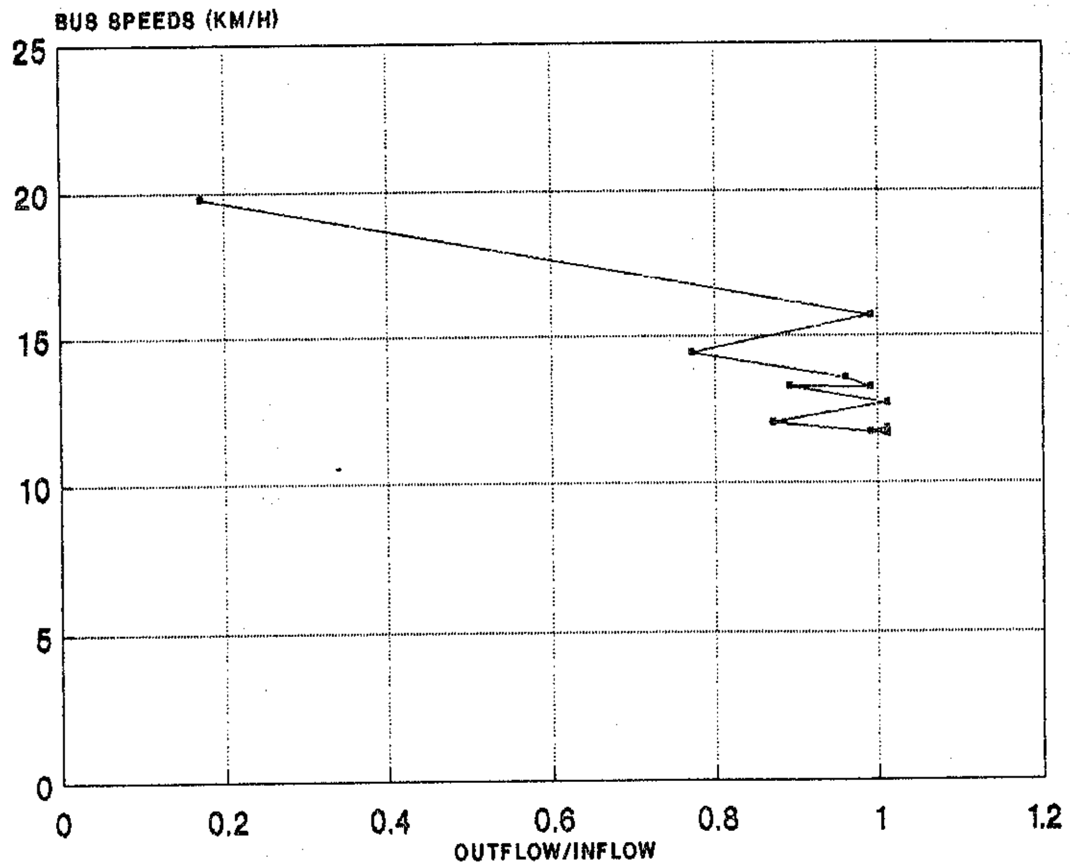
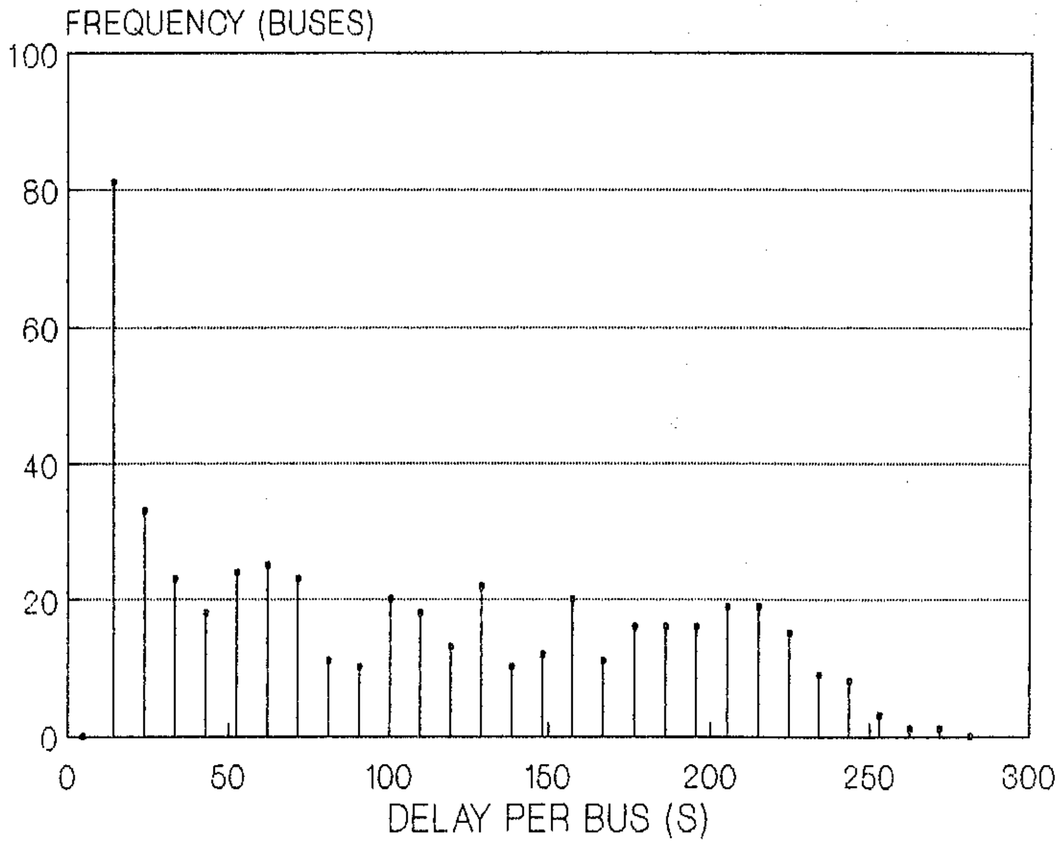


FIG: 5

CONVOY, ONLY WHEN FULL

AV.DEL=106.1(S)

V=498(B/H),MI.H.=3.(S),CONV= 6,GRP= 3

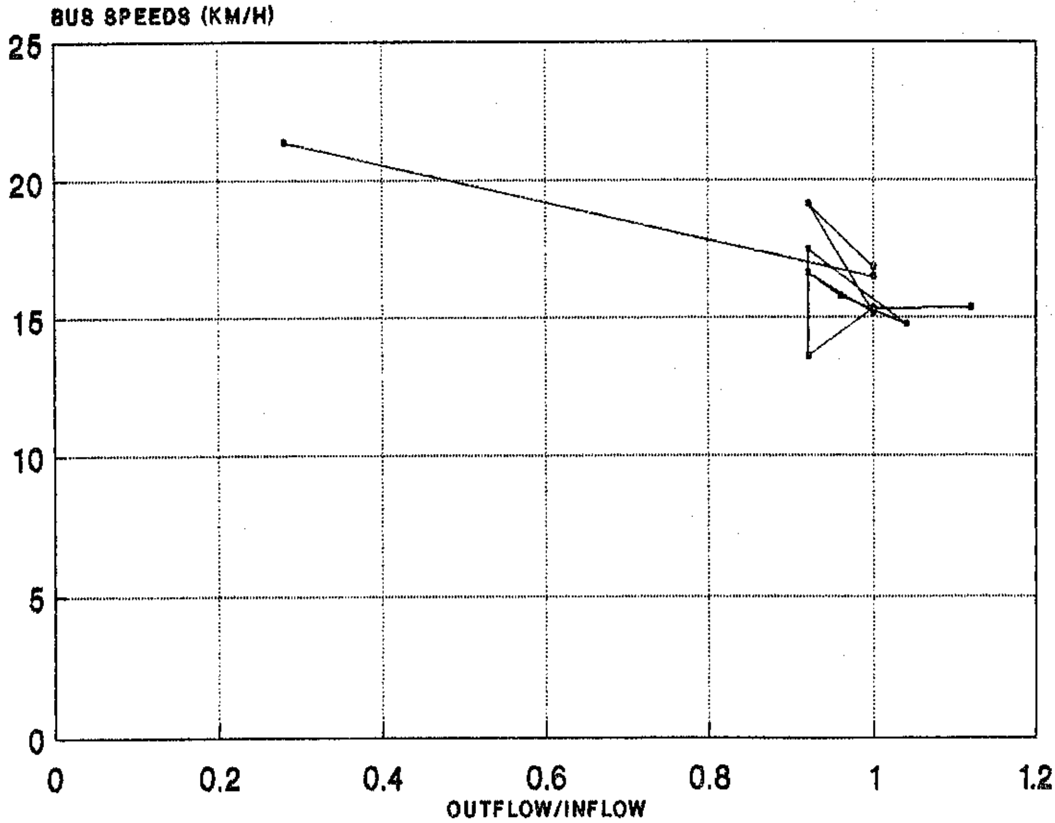


INITIAL DELAYS IN FORMING BUS CONVOYS

FIG. 6

NO CONVOY, NO INITIAL DELAYS

AV.SPEE= 16.2(KM/H), SD.SPEE= 5.3(KM/H)
H.FLOW = 300. (B/H), EXCLUD.= 0.(8)

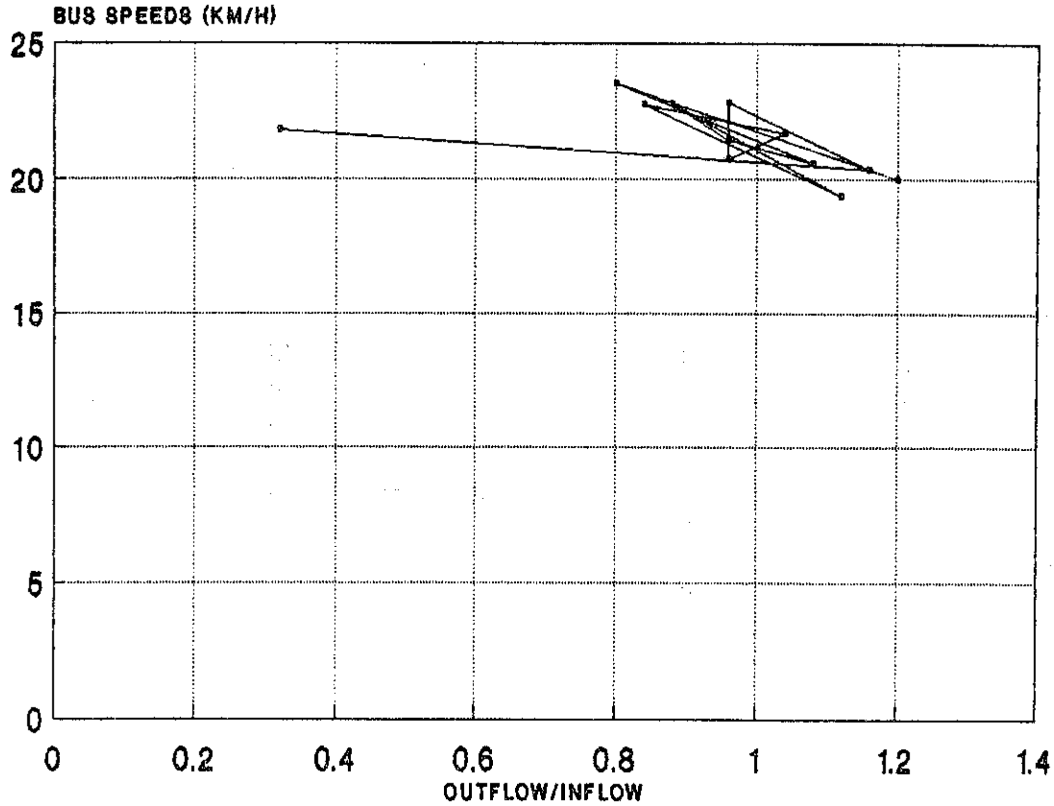


buses must stop at pre-defined bus bays,
although not being ordered in convoys;
constant boarding time for all buses

FIG. 7

NO CONVOY, NO INITIAL DELAYS

AV.SPEE= 21.3(KM/H), SD.SPEE= 6.9(KM/H)
H.FLOW = 300. (B/H), EXCLUD.= 0.(S)



4 buses being simultan. attended at stops, constant boarding time for all buses

FIG. 8

ANNEX 2

INPUT DATA REQUIRED BY CURRENT VERSION OF BLAST

INITIAL DATA

```
C              : SIMULATION TIME
C              : ROAD GEOMETRY
C                     : TRAFFIC SIGNALS
C                     : TRAFFIC CHARACTERISTICS
C                     : VEHICLE CHARACTERISTICS
C              : BUS OPERATION
C              : RANDOM NUMBER SEEDS
C              : LEVEL OF DETAILED OUTPUT
C
C
C            :SIMULATION TIME
C
line     SIT: TOTAL SIMULATION TIME (IN SECONDS), USUALLY=3600
C
C              : ROAD GEOMETRY
C
line    XL: TOTAL LENGTH OF THE ROAD (IN METRES)
C
line    NT: NUMBER OF TRAFFIC SIGNALS (MAX.= 40)
C
line    XT(I): LOCATION OF TRAFFIC SIGNALS, I=1,NT (IN METRES FROM ORIG.)
C
line    NB: NUMBER OF BUS STOPS (MAX.= 40)
C
line    XB(I): LOCATION OF BUS STOPS, I=1,NB (IN METRES FROM ORIG.)
C
C              : TRAFFIC SIGNALS
C
line    CT: COMMON CYCLE TIME (IN SEC);
C       GT: GREEN TIME FOR AVENUE (IN SEC);
C       AT: AMBER TIME FOR AVENUE (IN SEC).
C
line    OFFSETS
C                IT = 0  EXTERNAL INPUT
C                IT = 1  CALCULATE INTERNALLY, BANDWIDTH METHOD FOR BUSES
C                    OF(I): OFFSETS, I=1,NT (SEC) - not implemented yet
C
C              : TRAFFIC CHARACTERISTICS
C
line    XFL: HOURLY FLOW OF BUSES
C
C
line   TAU: SHIFT FOR NEG. EXPONENTIAL, EQUIVALENT TO MIN.
C           HEADWAY AT GENERATION (IN SEC); MUST BE >OR=
C           TO 1 SEC;
C
C      SAT: AVERAGE DISCHARGE BUS HEADWAY AT TRAFFIC SIGNALS
C           USED FOR ARRIVING PURPOSES ONLY WHEN APPROPR.
C           (SEC); MUST BE >OR= TO 3 SEC
```

```
C
line     KB: BUS INSERTION (RELEASE MECHANISM);
                      see text for details
C
C                 KB = 0  RANDOM DEPARTURES AT GREEN
C                 KB = 1  INCOMPLETE PLATOONS AT GREEN
C                 KB = 2  COMPLETE PLATOONS AT GREEN
C                 KB = 3  RANDOM DEPARTURES WHEN GENERATED
C                 KB = 4  COMPLETE PLATOONS WHEN GENERATED
C                 KB = 5  INCOMPLETE PLATOONS WHEN GENERATED
C
C        MQUEPL: MAXIMUM BUSES OF A SPECIFIC LETTER GROUP ALLOWED
C                TO QUEUE BEFORE INCOMPLETE PLATOON IS RELEASED (ONLY
C                EFFECTIVE WHEN KB=1 OR 5), IN BUSES;
C
C        XMDEPL: MAXIMUM DELAY ALLOWED TO FIRST BUS QUEUING
C                BEFORE INCOMPLETE PLATOON IS RELEASED (ONLY
C                EFFECTIVE WHEN KB=1 OR 5), IN SECONDS
C
C                  : VEHICLE CHARACTERISTICS
C
line     RAC: ACCEL SLOPE (M/S**3);
C        GSP: DESIRED SPEED (M/S);
C        GAM: AMBER REACTION (S);
C        GSD: STOPPING DISTANCE (M)
C
line     GSPD: STAND DEV SPEE (M/S)
C        GAMD: STAND DEV AMBER REACTION (S)
C
line     GMIS: MIN.DESIRED SPEED (M/S);
C        GMAS: MAX.DESIRED SPEED (M/S);
C        GMIA: MIN. AMBER REACT. (S);
C        GMAA: MAX. AMBER REACT. (S)
C
line     CB: LENGTH OF BUS (M);
C        WB: WIDTH OF BUS (M) - not being used by veh-following model
C
C           : BUS OPERATION
C
line       NP: NUMBER OF BUSES IN PLATOON;
C          LP: NUMBER OF LETTER GROUPINGS (=NP,NP/2,NP/3,...);
C          IP: OPERATION AT STOPS;
C                IP = 0, LOADING IN THE VICINITY OF STOPS
C                IP = 1, LOADING AT DESIGNATED BUS STOPS
C          NAS: NUMBER OF BUSES THAT NON-PLATOON BUS STOPS CAN SIMULTAN.
C               ATTEND; ONLY EFFECTIVE WHEN IP=0 (NAS<=10)
C
line       GBBO: BOARDING TIME PER PASS. (SEC);
C          GBMA: MAXIMUM NO OF PASS BOARDING AS FUNCTION OF MEAN;
C          GBDE: DEAD TIME AT STOPS (SEC);
C          GBRE: REDUCTION FACTOR WHEN SPECIFIC BAYS ARE USED;
C                = 1, NO REDUCTION
C                = 0.5, 50% REDUCTION, ETC...
C          IBCO: = 0, STOP TIME GENERATED FROM DISTRIBUTION
C                = 1, STOP TIME CONSTANT FOR ALL BUSES AND EQUAL TO MEAN
C
line(s)    GBPA(I): AVERAGE NO. PASSENGERS BOARDING AT STOPS, I=1,NB;
C          GBSD(I): STD. DEV. OF NO. PASS. BOARDING AT STOPS, I=1,NB
C              one line for each bus stop (1,...,NB)
```

```
C
line      IO: OVERTAKING AT BUS STOPS
C               IO = 0, NO OVERTAKING ALLOWED
C               IO = 1, OVERTAKING ALLOWED - not implemented yet
C         NOO: NUMBER OF BUS STOPS WHERE OVERTAKING IS ALLOWED
C
line(future)   KO(I): STOPS WHERE OVERTAKING IS ALLOWED, I=1,NOO
C
C           : RANDOM NUMBER SEEDS
C
line      GA,GB: CONSTANTS
line      GS(10): STARTING SEEDS
C
C
C         : LEVEL OF DETAILED OUTPUT
C
line   IWH: INDIVIDUAL HEADWAYS AND PLATOON ASSEMBLY, CHAN 4;
C         OPTION ON WHEN INPUT VALUE EQUAL TO 1
C      IWP: INDIVIDUAL KINEMATIC PERFORMANCE FOR PLOTING, CHAN 20;
C            = 0, NO PLOTS
C            = 1, TIME VS. DISTANCE
C            = 2, TIME VS. SPEED
C            = 3, TIME VS. ACCELERATION
C      IERR: WRITE A SERIES OF DETAILS TO CHAN 4, USEFUL TO DETECT
C         ERRORS. IERR IS THE STARTING TIME TO WRITE INFORMATION
C
line   IPLTIM: IF IWP NE 0, TIME TO START PLOTING;
C      IFITIM: IF IWP NE 0, LENGTH OF PLOTING (IFTIM <= 240 SEC);
C      IPRIM:  IF IWP NE 0, FIRST BUS TO PLOT (NOTE THAT ONLY
C         THIS PLUS THE FOLLOWING 7 BUSES WILL BE PLOTTED)
C
line   TTII: TIME TO START WRITING DETAILED VEH-FOLLOWING INFORMATION;
C      IFOC: BUS TO HAVE INFORMATION
C
line   TFIR: TIME TO START COLLECTING FINAL RESULTS (I.E. SPEED-FLOW PLOTS);
C      TINT: INTERVAL TIME FOR AVERAGING
```

AN EXAMPLE OF AN INPUT DATA FILE

```
3600
1250
3
200,800,1250
2
450,1050
60,36,4
0
0,15,30
300
3.,3.
4,3,30
0.08,10.5,3.47,1.52
1.4,1.28
7.7,13.3,2.19,4.75
10.7,2.73
6,3,1,0
2.,2.5,3.,1.,1
5,1.5
6,1.4
0,0
2147483647,16807
1,2,3,4,5,6,7,8,9,10
0,2,3600
3600,40,1
3600,1
0,300
```

ANNEX 3

PRINTED OUTPUT OF BLAST

```
***********************************************************************
                         BLAST, version=   1.00

  a model for designing bus lanes under high-flow conditions
           author: Luis Antonio Lindau
                   CPGEC/UFRGS
                   Caixa Postal 303 - Ag. Central
                   Porto Alegre, RS
                   BRAZIL
                   telex: Brazil 051-5352 FUNC BR
***********************************************************************
 ***  INPUT DATA  ***

   AS LOADING AT DESIGNATED BUS STOPS WAS SELECTED,
   PLATOONS AND LETTER GROUPINGS MUST BE USED
 TOTAL SIMULATION TIME (S) =        3600.000000
 INFORMATION ABOUT THE ROAD TO BE SIMULATED
     TOTAL LENGTH OF THE ROAD(M) =      1250.000000
     NUMBER OF TRAFFIC SIGNALS =               3
     LOCATION OF TRAFFIC SIGNALS(M) =
             200.000000      800.000000      1250.000000
     NUMBER OF BUS STOPS =              2
     LOCATION OF BUS STOPS(M) =
             450.000000     1050.000000
     COMMON CYCLE TIME(S) =          60.000000
     GREEN TIME(S) =          36.000000
     AMBER TIME(S) =           4.000000
     OFFSETS EXTERNALLY INPUT (S)
          0.000000E+00        15.000000        30.000000
   TRAFFIC CHARACTERISTICS
        HOURLY FLOW OF BUSES =        300.000000
        MINIMUM HEADWAY AT GENERATION =          3.000000
        AVER.DISCH.HEADW.AT SIG.(GENER ONLY) =          3.000000
        NUMBER OF BUSES BEING SIMULATED =       300.000000
   RELEASE MECHANISM
        COMPLETE PLATOONS WHEN GENERATED
    GENERAL VEHICLE CHARACTERISTICS
        ACC.SLOPE(M/S**3) =     8.000000E-02
        DES.ACCEL(M/S**2) =          1.296148
        DES.SPEED(M/S)    =         10.500000
        AMBER REACTION(S) =          3.470000
        STOPPING DIST.(M) =          1.520000
        ST.DEV SPEED(M/S) =          1.400000
        ST.DEV AMBER(S)   =          1.280000
        MIN.DES.SPEED(M/S)=          7.700000
        MAX.DES.SPEED(M/S)=         13.300000
        MIN AMBER REACT(S)=          2.190000
        MAX AMBER REACT(S)=          4.750000
        LENGTH OF BUS(M)  =         10.700000
        WIDTH OF BUS(M)   =          2.730000
    BUS OPERATION
        AVERAG BOARD. TIME PER PASS(S) =          2.000000
        DEAD TIME AT STOPS(S) =          3.000000
        REDUCTION FACTOR FOR BOARD. TIME=          1.000000
```

```
  CONSTANT BOARDING TIME SELECTED FOR ALL
   AVERAGE NUMBER OF PASS. BOARDING AT EACH STOP
       5.000000         6.000000
   LOADING ONLY AT DESIGNATED BUS BAYS
   BUSES SIMULTANEOUSLY ATTENDED =           6
   NUMBER OF BUSES IN PLATOON =           6
   NUMBER OF LETTER HEADINGS =           3
BUS STOP OPERATION
   NO OVERTAKING IS ALLOWED
RANDOM NUMBER SEEDS
        2.147484E+09    16807.000000
     1.000000         2.000000         3.000000         4.000000
   5.000000         6.000000         7.000000         8.000000
   9.000000        10.000000
OUTPUT REQUIRED
      KINEMATIC CHARACT FOR PLOTS
```