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Bus Stop Congestion and its Contribution to Delay

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ABSTRACT

It has been suggested that bus stops play an important part in determining the level of delay at urban links. Congestion at bus stops, interaction between buses and other traffic due to bus stopping at a bus stop, and the location of the bus stop in any link are some of the main features influencing this delay.

This paper will therefore discuss these features with the aid of a computer simulation program written by the author. This computer simulation model considers a bus stop located in a dual-carriageway with traffic signal at the downstream end as well as the upstream end of the link. The behaviour of this system were simulated microscopically in the model where the activities of each passenger, bus and car are studied for each second of the simulation period. The corresponding delay to passengers, cars and buses and the average queues for passengers and buses were then found for a range of values for the contributing factors. Such contributing factors considered in this model are level of demand, frequency of buses, location of bus stop (mid link, nearside or farside of the junction), average flow rate in the link, and signal timings.

The structure and the main feature of this program will be discussed in this paper which will conclude with some results from this simulation program and a few general conclusions.

1. INTRODUCTION

A bus stop to most people is mere transport infra-structure, where buses stop to board or alight passengers. What most people do not gather is the fact that a bus stop, by its nature contributes to bus unreliability, and delay to patrons and other road users.

It is fair enough, if the general public are not sensitive to this critical nature, but what is even more depressing is the lack of studies taken up by transport experts in this area. By not making enough

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research in the nature of bus stops, the chances of alleviating the problems related to the design and characteristics of bus stop are slim. The irony in this matter is that most experts agree that bus stops can increase the delay to passengers, buses and other vehicles, yet not much interest is shown in this area. The Highway Capacity Manual advocates this claim and asserts the bus stops may cause delay if not designed or located properly (Transportation Research Board, 1985).

Congestion at bus stops may be either caused by the passengers behaviour, the queueing discipline of buses, interaction between buses and other traffic when a bus is stopping, or the location of the bus stop in the link. These effects may be different if some or all of the influencing factors such as level of demand, frequency of buses, average flow rate, and signal timings change.

It is the objective of this study to investigate the nature and activities relating to bus stops and their effects on delay to passengers, buses and other traffic involved. It is hoped to shed some lights on questions such as

- i) Is the location of the bus stop appropriate to the surrounding conditions ?
- ii) Does the frequency of buses and level of demand contribute to the extra delay ?
- iii) What effects do different flow levels have ?
- iv) What is the best design for the bus stop to increase efficiency and decrease congestion in and around the bus stop ? (Sadullah, 1989)

The microscopic nature of the study suggests that a simulation model is the best way to represent the system, and to analyse the nature of bus stops and their corresponding delay contributions.

2. EFFECTS OF BUS STOP ON DELAY

2.1 Introduction

To be able to study the effects of bus stop on delay, it is thought to be wise to give a general review on the different characteristics of bus stops and other contributing factors such as vehicle design and traffic flow. To get a better understanding on the types of delay possibly suffered, a brief explanation on them will also be given.

2.2 Definition of Delay

The definition of delay is often arbitrary according to the situation and objectives of the study.

Delay to passengers is the usual performance indicator for any bus service, therefore it often gets the highest consideration by the planners or operators. Delay to passengers can be represented by one or a combination of the following time parameters involved in the journey

of a passenger. The average walking time of a passenger from origin to the bus stop is the first stage of his/her journey, and is often included in the definition of delay to passengers. The next stage, which is the time from the passenger's arrival at the bus stop until the intended bus is available, is called the waiting time. This average waiting time is the most widely used indicator for bus services (Chapman et al,1976). In general terms, the Average Waiting Time(AWT) can be expressed as a function of the bus headway, and given by

$$AWT = \frac{h}{2} \left(1 + \frac{\text{var } h}{h^2} \right)$$

where h is the headway of buses. This expression is only valid for random passenger arrivals, and assumes that passengers can board the first desired bus that arrives (Holroyd & Scraggs, 1966). However, for a detailed observation, this expression is insufficient, thus methods such as simulation models would be more appropriate. Other considerations such as the boarding and alighting times as well as the in-vehicle time should also be given.

Time parameters involved in the definition of bus delay include those times spent at bus stops and in between stops. Stationary time at bus stops varies according to several factors. Among them are the door configuration, type of operation (One person or two persons operated), and the fare system. While the time spent between stops, depends on the number of red lights encountered, traffic condition, and the congestion level upon entry of the next bus stop.

Like buses, cars or other traffic can also be subjected to delay due to the existence of buses on the same roadway. This problem will be aggravated in areas around a bus stop especially if it has on-street berths. This is a major problem in most developing countries where buses are in abundance, and perhaps because of competitive pressures, and because bus drivers are more unruly.

2.3 Bus Stop Characteristics and their Influence on Delay.

The characteristics of a bus stop play a vital role in all matters concerning bus operations. All parties involved: passengers, bus operators, and other road users are vulnerable to being the victims of poor design and wrong location of bus stops. On the other hand, a good design and a right location will help smoothing not only the bus operation but also the flow of other vehicles in the link.

The first aspect of bus stop characteristics is its design. A good design of bus stops usually include facilities for both passengers and buses. An equilibrium between the level of provision for bus efficiency and for passengers safety is always sought. To understand the complex behaviour at bus stops, Gibson et al (1989) have suggested that different elements specifying a bus stop need to be characterised, which

are as follows;

- a) the bus stop area - appropriate location
- b) berth configuration - on-street or off-street
- c) use of berth - with restriction or free usage
- d) single or multiple stops
- e) character of the stop - mandatory or request stop, and
- f) entry and exit discipline.

The above characteristics may influence delay in one way or another. When designing for bus stops, provision for passengers should always be considered in order to avoid unnecessary boarding delays as well as to prevent any accidents.

The next characteristic of a bus stop concerns its location on the roadway. In general, bus stops are placed either at mid-link positions, near-side or the far-side of the junction. There have been many claims on the best location for a bus stop but none of them has convincingly proven that their claim is true. Lindau(1983) in his work, summarises the major factors affecting the choice of stop locations. They are as follows;

- a) bus routing patterns - possible delay caused by location to
 - i) through buses
 - ii) right turning buses
 - iii) left turning buses
- b) convenience to passengers
- c) type of traffic control
- d) safety
- e) turning movements.

The best location therefore should have considered all the above.

Bus stop spacing is another characteristic that might influence delay, especially on the travelling time of buses. The spacings to be chosen again has to satisfy both the passengers (for having shorter walking time) and the operators (for keeping the operating cost low).

Other characteristics that might influence delay include the vehicle characteristics (vehicle size, door configuration, travelling speed, etc), the operating characteristics (frequency, fare system, special operations, etc), passenger demand characteristics (variation in demand), street traffic characteristics (traffic flow), and the junction traffic signal timings.

3. SIMULATION MODEL DESCRIPTION

3.1 Introduction

A microscopic model is suitable for studying the activities at a bus stop in detail, as well as for studying the possible interaction between passengers, buses and other traffic on a link due to the existence of a bus stop. The simulation model was written in Turbo Pascal programming language (version 4), and is usable on IBM PCs or compatibles. The

framework and the concepts behind the model's development will be discussed next.

3.2 Framework of the Model

This model has been designed to replicate a real system comprising of a one-berth bus stop in a dual-carriageway link with traffic signals at both end junctions. Passengers, buses, and other traffic activities (including interaction between them) are represented for each second of the simulation period. For simplicity, cars have been used to represent the other traffic throughout the model. Most of the parameters involved were determined stochastically through the aid of the random number generator provided within the machine on which the model will be running.

The model needs basic information on the system before being able to simulate it. It starts with assigning the initial positions of cars on the link at random. At the start, the signal stage at both junctions is green. Cars will then move along the link at a constant speed until they meet some impediments in front, thus forcing them to stop. These impediments may be the result of queuing cars stopping at the signal during the effective red stage, or may be the result of a bus stopping at the bus stop. At the same time, passengers and buses will be arriving at random throughout the simulation period. All the activities, ie. at the bus stop, interaction between buses and cars as well as the condition at the downstream end of the link will be simulated. The flow chart for the framework is shown in figure 1

Results to the model will give detail information on the bus activities throughout the simulation period. Other important results for passengers, buses and cars, and the saturation flow are also given.

The following sections will discuss the development of the simulation model in greater detail.

3.3 Representation of the Link

All the activities to be simulated will take place on the link. Therefore, a method had to be devised so that these activities may be simulated with ease. The factors considered were as follows;

- i) to allow cars and buses to move along the link
- ii) to indicate whether the space in front is available for these vehicles to move forward
- iii) to allow overtaking if vehicles are halted
- iv) to allow queueing and
- v) to keep track of the exact location of each vehicle for each second of the simulation period.

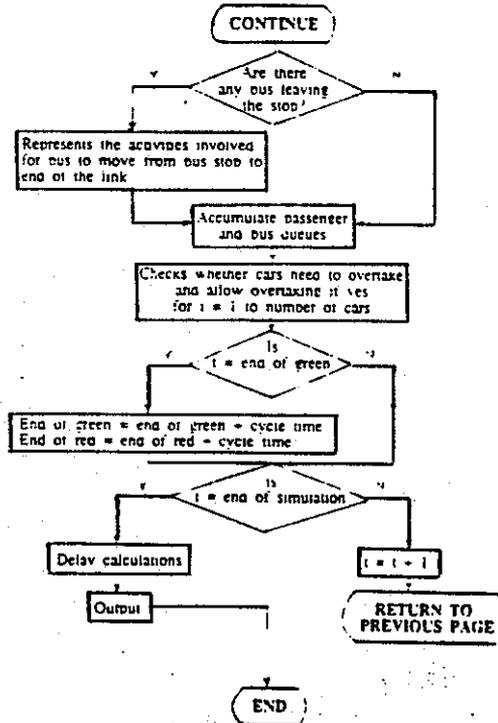
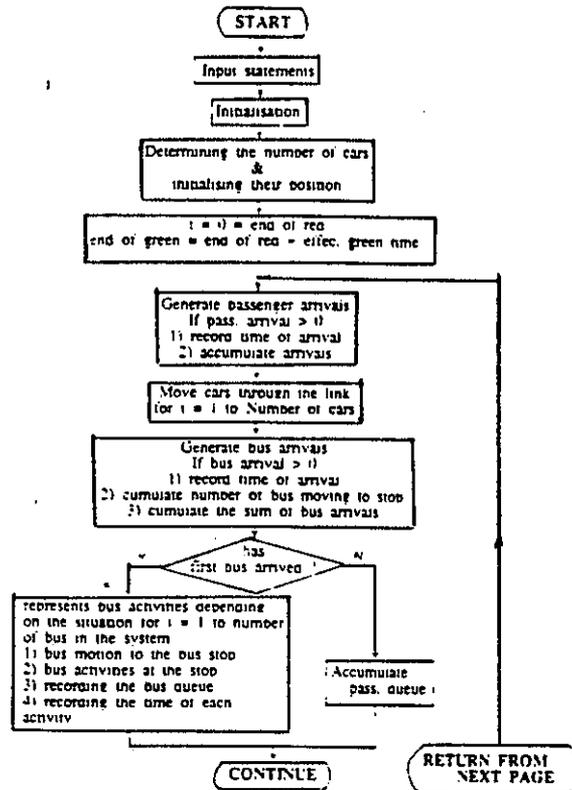


figure 1 : framework of the simulation model

With these factors to consider, it was decided to use a grid system to represent the link. The grid system will be treated as a matrix of $n \times 2$ dimensions in the source code. The value 2 represents the two lanes in the link and the value n depends on the length of the link and the length of each cell in the grid system.

During execution, a record for each cell of the grid system is taken for each second. The record indicates the availability of the cells, and if it is not available, the time at which the cell was occupied is also recorded. With these records, the program will scan through the entire link and hence will be able to exercise the moving procedures of the vehicles. Before the recording of these cells can be done, an assignment procedure has to be carried out to correlate between the position of each vehicle in terms of distance along the link from entry and the corresponding cell in which it occupies. Figure 3 illustrates the grid system.

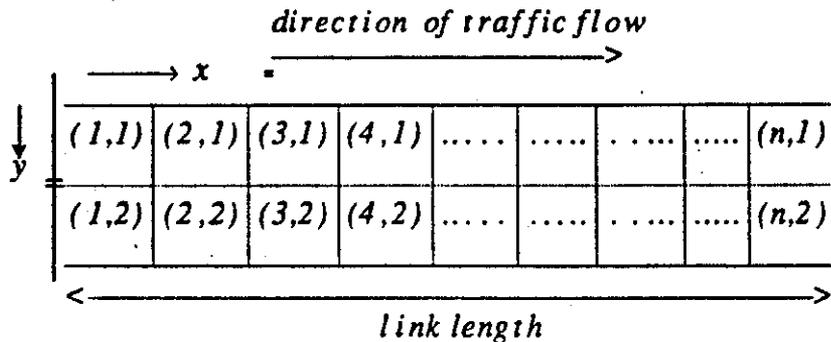


figure 3 Illustration of the grid system

3.4 Representation of the Bus Stop

The type of bus stop represented in the model is of the single, on-street-berth type. The bus stop, depending on the location, which will be determined by the user will have different effects to all parties involved.

The bus stop in this model is of the compulsory-stop type, therefore all buses entering the road section under consideration will be stopping at the bus stop. The queueing discipline is the FIFO (First in, First out) type, therefore buses will take turns to dock at the berth according to the order of arrival.

Buses are to alight and board passengers only when they are safely in the berth, and passengers can only board the bus after all passengers wishing to alight have done so. The bus will leave the stop when there are no more passengers wishing to board or when the bus is full, depending on whichever comes first.

3.5 Representation of the Activities

A method need to be devised so that the activities of all three subjects can be simulated simultaneously. For further explanation, this section will be divided into subsections which deals with the representation of cars, buses and passengers respectively.

3.5.1 Representation of Cars

The same number of cars will be used throughout the model and they are designed to go in a loop, therefore allowing an approximately constant car flow rate in the link. The constant number of cars is determined in the following manner :

$$\text{number of cars} = \frac{\text{average car flow rate}}{\text{average car speed}} \times \text{link length} \quad (2)$$

These cars, designated by the order of sequence by which they were initially generated, will move along the link and will return to the beginning of the link once they leave the road section.

The simulation model will commence with the initial positioning of the cars which was done randomly. Two matters to be considered is the longitudinal position along the link and the lane which it is in (the nearside or farside lane). These initial positions will then be transformed into the cell of the grid system through the assignment procedure.

From this initial positions, the cars will move along the link with the average speed designated to it through the input statements. The similar assignment procedure will be used to transform the position of the cars onto the cells in the grid system. It will keep moving until it meets an occupied cell. Under this condition, the car will be allowed to overtake if it has been in the same grid for more than one second, and if there is enough space to overtake.

At the downstream junction, a counter was placed to determine the actual number of cars using the link as well as the saturation flow of the junction. There are also parameters to indicate the time at which each car enters and exit the link. Therefore, for each entry and exit of a car, a corresponding in-link time can be determined. From the accumulation time, the average time spent by each car in the link can be determined, and this value can be used to define delay for cars.

3.5.2 Representation of Buses

The attention in this model is concentrated on activities involving buses, be it at the stop or on the link. With the RECORD facilities in Turbo Pascal, the model is able to keep track of each bus that enters the link, including all the activities it is involved with.

Given the mean rate of arrival through the input statement, the model will generate the buses arrivals at random following a Poisson distribution. The next second after its arrival, the bus will be moving along the link towards the bus stop provided that the grids in front is free. Buses are restricted to the nearside lane of the link only and are not allowed to overtake any vehicles. Movements along the link and the assignment procedures remain the same as for the cars.

The time spent at the bus stop depends on the number of passengers alighting and boarding, and this time is called the bus dwell time. After the leaving criteria has been achieved, the bus will leave and continue moving downstream and will only stop if it confronts an occupied cell upfront, which is likely to be the result of the red light at the downstream junction.

With the RECORD facilities, the model is capable of recording the time parameters for each bus which will be very important in the definition of delay.

3.5.3 Representation of Passengers

Passengers behaviour at the stop determines the amount of time a bus spends at the stop, thus their representation need to be considered carefully too. In this model, passengers are generated at random with Poisson arrivals depending on the mean rate of arrivals given by the user. Upon arrival, a passenger will wait for a bus and forms a queue if there is no bus at the bus stop. When the bus arrives and docks, the queuing passengers will have to wait for all alighting passengers to finish before they can board. It was assumed that passengers will board the first bus that arrives and will be able to board the bus as long as the capacity of the bus has not been reached. The activities of each passenger are also kept in the record.

4. RESULTS FROM SIMULATION MODEL

As a basis for analysis, a survey was made for this study. The data from the site which was the Cambridge Circus stop on Charing Cross Road (between Shaftesbury Avenue and Oxford Street) were used and manipulated for this analysis. Information from the survey was also used to validate the simulation model. The model was found to yield an error of about 13%. This difference is due to the fact the the model was not able to replicate the real situation fully (i.e. a lot of assumptions had to be taken)

A summary on the results obtained through the model on the effects of variations in demand levels, service levels, stop locations and flow rates on passengers, buses and cars will be given here.

Table 1 is the tabulated results for all the analysis made for this study. From the results and with the help of graphic representations, a few inferences and conclusions under the topic of bus stop congestion and its contribution to delay can be made.

The analysis has been divided into three sub-divisions: frequency and level of demand, bus stop location and car flow rate.

a) Frequency and level of demand

It was found that delay to buses increases when the level of demand increases. It also increases when the bus frequency decreases. The extra dwell time resulted from these varying situations was clear to be the main contributor to the additional delay suffered by the buses. Regardless of the combinations, if the dwell time experienced by buses at bus stops are increased, the delay for buses are also bound to increase. Therefore, a balance between the bus frequency and the level of demand need to be achieved in the bus operation to minimise delay. This result can be inferred from figure 4 and table 1(a).

Car Flow Rate Average Bus Delay (definition 1)

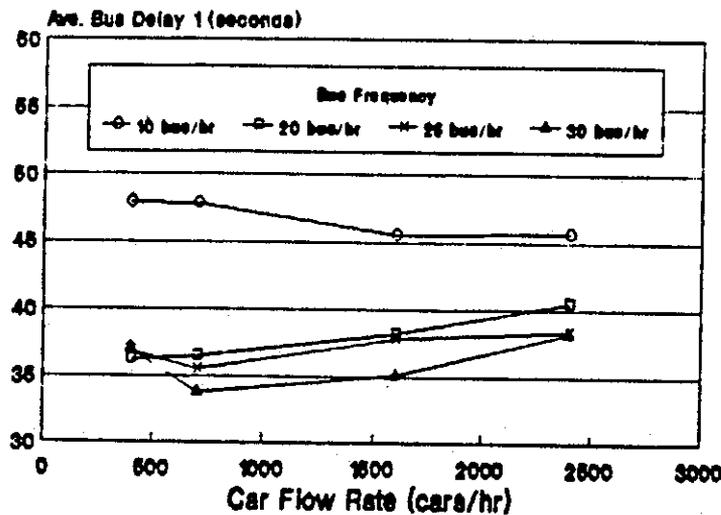


figure 4

It was also found that the occurrences of buses queueing to enter a bus stop was found to increase the amount of delay suffered by buses. This situation is likely to happen when the frequency of buses stopping at the stop exceeds its berth capacity. It is therefore imperative to match the bus frequency with the bus stop's capacity if excessive delays are to be avoided. This queueing-caused delay however becomes less dominant when the level of demand is exceptionally high. These findings indicate that for a certain type of bus stop, there is an upper limit to the frequency of buses and the level of demand, beyond which buses will suffer extra delays.

The percentage of passengers able to board the first bus that arrives at the stop was found to have significant influence on the passengers

waiting time. If the percentage of able-boarders are high, the waiting time for passengers are not much affected by the level of demand, as long as it is within the acceptable limits. This finding, in turn points to the fact that for a given level of demand, the suitable type of bus to be used can be selected according to the amount of average waiting time it yields. The passenger waiting time however is highly dependent on the bus frequency with higher bus frequencies causing less delay to passengers at bus stops.

The average passenger queue waiting at bus stops has been found to be greatly influenced by the level of demand and the bus frequency. Passenger queue is directly related to the level of demand but inversely related to bus frequency.

b) Bus stop location

Delay to buses in a link is higher when the bus stop is located at junctions when traffic flow is high. However, the difference between delay incurred by a farside and nearside junction bus stop is not clear from the analysis. Figure 5 shows this relationship.

Bus Stop Location Average Car Delay

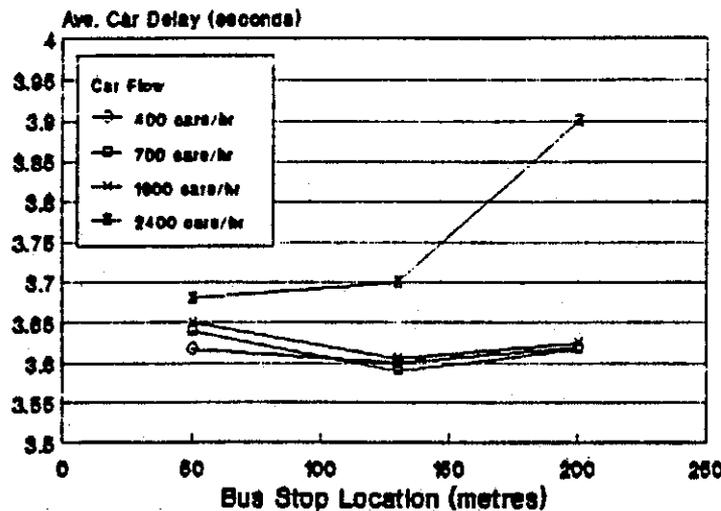


figure 5

The difference in dwell time is the more dominant factor influencing the bus delay if compared to the location. However, all possible steps to reduce delay have to be taken into consideration, thus the proper location of bus stops is also an essential consideration.

The bus stop locations was also found not to be the dominant factor in determining the passenger waiting time. Dwell time for buses still gain the upper hand, which suggests that the balance between bus frequency and level of demand should get the highest priority in the operator's list of strategies.

Delay to cars and other traffic was found to be much higher when the bus stop is located at junctions. At exceptionally high traffic flow, bus stops located at the nearside of the junction significantly increases the delay to cars. Figure 6 illustrates this.

Bus Stop Location Average Bus Delay (definition 1)

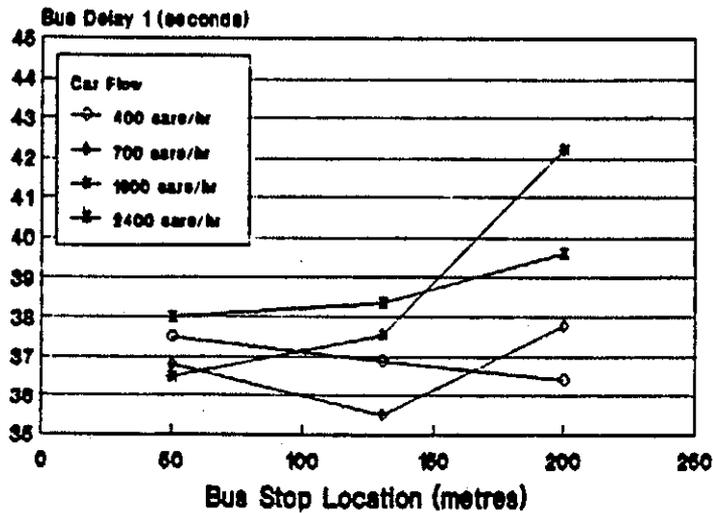


figure 6

c) Car flow rate

For high frequency buses, increase in traffic flow will increase the amount of delay suffered by buses. However, when bus frequency is low, the time spent at the bus stop emerges as the dominant factor influencing bus delay. Refer to figure 7 for illustrations.

Level Of Demand Average Bus Delay (definition 1)

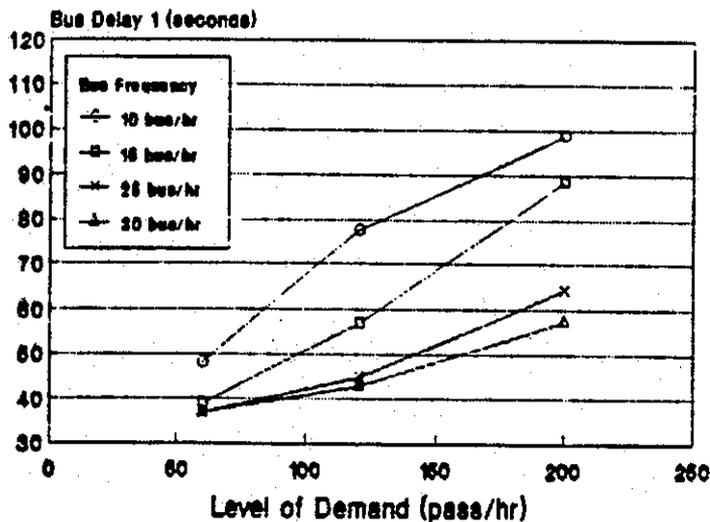


figure 7

Frequency and Level Of Demand

Demand	Car			Bus		Passenger			
	Delay <u>pass</u> hr	Delay1 (sec)	Delay2 (sec)	Queue (sec)	Dwell time (sec)	headway (sec)	waiting time (sec)	queue	‡ boarded
Bus frequency = 10 bus/hr									
60	3.59	47.87	36.63	0.0009	38.9	421.29	356.21	5.29	91.0
120	3.59	77.60	43.30	0.0223	61.9	428.10	389.80	12.0	92.0
200	3.60	98.70	53.50	0.0329	72.9	367.10	358.40	17.5	89.0
Bus frequency = 15 bus/hr									
60	3.58	38.80	35.30	0.0037	31.1	268.20	274.30	4.10	95.0
120	3.57	56.90	44.50	0.0416	40.0	230.10	254.90	7.40	94.0
200	3.59	88.30	51.20	0.0462	64.7	302.90	285.90	12.7	93.0
Bus frequency = 25 bus/hr									
60	3.60	36.90	39.60	0.0152	24.9	152.10	163.90	2.30	98.0
120	3.66	44.84	38.23	0.0190	34.2	168.77	174.69	4.93	95.0
200	3.64	64.45	46.75	0.0611	45.2	168.96	197.34	8.48	95.0
Bus frequency = 30 bus/hr									
60	3.61	37.04	39.92	0.0154	24.7	124.56	119.20	1.80	97.0
120	3.58	42.95	41.11	0.0292	29.4	120.86	112.30	3.00	99.0
200	3.60	57.31	44.16	0.0654	40.71	133.98	138.60	6.00	96.0

table 1(a)

Location

location (metres)	Car			Bus		Passenger		
	Delay (sec)	Delay1 (sec)	Delay2 (sec)	Queue	Dwell time (sec)	headway (sec)	waiting time (sec)	queue
Car flow rate = 400 cars/hr								
50	3.62	37.50	38.50	0.0232	26.6	164.10	161.50	2.50
130	3.60	36.90	39.60	0.0152	24.9	152.10	163.90	2.30
200	3.63	37.53	38.99	0.0329	26.1	160.00	178.90	2.80
Car flow rate = 700 cars/hr								
50	3.64	36.80	40.00	0.0265	24.4	126.90	132.20	2.00
130	3.59	35.50	38.73	0.0158	24.3	140.10	141.24	2.21
200	3.62	37.80	40.50	0.0167	24.9	140.20	149.00	2.20
Car flow rate = 1600 cars/hr								
50	3.65	36.50	38.20	0.0191	25.9	151.00	131.10	1.90
130	3.61	37.55	40.22	0.0185	24.9	139.07	134.20	2.00
200	3.63	42.20	43.30	0.0206	26.5	144.60	135.30	2.10
Car flow rate = 2400 cars/hr								
50	3.68	38.00	41.01	0.0335	24.59	136.61	144.80	2.40
130	3.70	38.35	39.76	0.0178	26.19	159.94	154.20	2.30
200	3.90	39.62	39.76	0.0142	27.46	177.95	160.60	2.60

table 1(b)

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Sample Output

***** THE INPUT PARAMETERS *****

Period of simulation : 3600.0 seconds
 Period of Interval : 1.0 seconds

Bus Stop Distance From Entry (metres)	Length of Link (metres)
130.0	230.0
Cycle Time (seconds)	Eff GreenTime (seconds)
76.0	55.0

PASSENGERS

Arrival Rate (pass/hr)	Marg Alight Time (sec)	Marg Board Time (sec)
60.0	1.0	2.0

BUSES

Arrival Rate (buses/hr)	Capacity	Ave Speed (km/h)
10.0	70	30.0

CARS

Average Flow Rate (cars/hr)	Average Car Speed (km/h)
600.0	40.0

***** THE RESULTS *****

BUS ACTIVITIES

Bus	ArrivalTime (sec)	DockingTime (sec)	DwellTime (seconds)	LeaveStopTime (sec)	LeaveSectionTime (sec)	InLinkTime (seconds)
1	192.0	209.0	21.0	230.0	243.0	51.0
2	645.0	662.0	55.0	717.0	730.0	85.0
3	857.0	874.0	40.0	914.0	927.0	70.0
4	863.0	915.0	7.0	922.0	936.0	73.0
5	910.0	927.0	28.0	955.0	989.0	79.0
6	931.0	956.0	25.0	981.0	995.0	64.0
7	1001.0	1018.0	14.0	1032.0	1065.0	64.0
8	1329.0	1346.0	28.0	1374.0	1387.0	58.0
9	1862.0	1879.0	44.0	1923.0	1936.0	74.0
10	2106.0	2123.0	15.0	2138.0	2151.0	45.0
11	2707.0	2724.0	45.0	2769.0	2782.0	75.0
12	3172.0	3189.0	52.0	3241.0	3269.0	97.0

FINAL RESULTS

Passengers

Total Arrivals	Total Left	Ave Waiting Time (seconds)	Ave Queue
57	53	242.7	3.6

Buses

Total Arrivals	Total Left Stop	Total Left Section	Headway (sec)	Average Dwell Time
12	12	12	300.0	31.2
Ave Occupancy	Time Thru Link (secs)	Delay 1 (seconds)	Delay 2 (seconds)	Average Queue
26.5	69.6	42.0	38.4	0.0131

Cars

Actual Flow (cars/hr)	Ave Time Through Link (seconds)	Actual Ave Speed (km/h)	Delay (sec)
427	24.3	34.1	3.6

Saturation Flow (veh/hr)
623.2