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PART-TIME ENTRY TRAFFIC SIGNAL CONTROL EFFECT ON ROUNDABOUT CAPACITY AND PERFORMANCE

BY

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تأثير اشارات المرور الضوئية اثناء اوقات الذروة
على سعة واداء التقاطعات الدائرية

يهدف هذا البحث الى دراسة ومعرفة تأثير نظام تشغيل التقاطعات الدائرية بواسطة اشارات مرور ضوئية فقط اثناء الذروة على سعة وكفاءة تشغيل مثل هذه التقاطعات.

ولقد قام الباحث بتحليل المعلومات الميدانية على احدى هذه التقاطعات والتى تم تجميعها قبل وبعد ادخال هذا النظام فى التشغيل بثلاث سنوات فى مدينة شيفلد بالمملكة المتحدة وبدراسة وتحليل احجام المرور الداخلة من كل الطرق المؤدية الى التقاطع وتوزيع ازمنة التقاطر للمركبات فى داخل التقاطع الدائرى وكذلك نسب المركبات الداخلة والمحققة للفراغات المختلفة فى تيار المركبات الموجود بالصينية الدائرية امكن التوصل الى عمل مقارنة بين قبل وبعد ادخال هذا النظام الجديد فى عملية تشغيل التقاطعات الدائرية المزدحمة داخل المدن الكبيرة والتى اصبحت بها اختناقات مرورية فى معظم عواصم المحافظات خصوصا فى ساعات الذروة .

كذلك قام الباحث بتحليل بيانات الحوادث قبل وبعد ادخال النظام الجديد واوضح مدى تأثير هذا النظام فى التشغيل على نسب حوادث المرور بالتقاطع. وخلاصة البحث توضح ضرورة واهمية هذا النظام الجديد فى تحسين تشغيل ورفع كفاءة التقاطعات الدائرية كما اوصى الباحث بعمل دراسة لقياس اطوال طوابير السيارات والتأخيرات عند مداخل الطرق الى مثل هذه التقاطعات حتى تتضح اكثر اهمية هذا النظام فى التأثير على اداء وسلامة الحركة المرورية عند هذه التقاطعات الدائرية .

Abstract :- In this paper, study of the effect of part-time traffic signal operation at some approaches to one of the busiest roundabouts in the City of Sheffield (U.K) has been carried out. 'Before' and 'After' situations of this roundabout performance and capacity are presented and compared. It is noteworthy that the introduction of the part-time signals has led to considerable increase in the entry capacity in the peak periods from most approaches to this roundabout. Moreover, these signals have proved to be the most effective and economical solution for sharing out or balancing the entry flows between different approaches of the roundabouts.

(1) INTRODUCTION

Since the introduction of the offside-priority rule in roundabout operation in the late of 1960's and the early of 1970's, different developments in both operation systems and geometric layouts have been adopted in practice [1]. These developments usually aim at smooth operation as well as improving the performance and increasing the entry capacity of roundabouts. Nevertheless, there are still some problems arising from unbalanced entries flows which in most cases result in long queues extending for a considerable distance and cause unbearable delays to the waiting vehicles. This vehicles queue backup might cause blocking in the preceding junction. It should be mentioned that this situation is frequently observed in central areas of large cities in particular during the peak periods.

In order to avoid such problems, part-time traffic signals have been nstalled on the approaches to these roundabouts in order to control entry lows on these approaches in the favour of another heavy flow approaches iich are already suffering from extensive delays and long vehicles queues. ı addition, the installation of these traffic signals allows the undabout to be compatible with the nearby signal-controlled intersections Urban Traffic Control (U.T.C) system is to be utilised in the whole area ıder consideration . Due to the above mentioned problems much emphasis has en paid to the traffic management and effective use of computer control traffic signals to improve the flow through these roundabouts [2]. rt-time traffic signal operation on some approaches is considered one of iese actions which are thought to improve the performance of the undabout and make its operation much easier and smoother than before. reover, these signals on tha roundabouts entries help to separate the nflicts between the vehicular movement particularly when there are no destrian subways.

City of Sheffield (in the U.K) has introduced the part-time signal ntrol scheme at a number of roundabouts. One of these sites is the Moore reet roundabout which was basically suffering from unequal amount of lay occurred at the different entries during both morning and evening ak hours. Therefore, it was basically intended to redistribute the delay d improve the performance of this roundabout in terms of queue lengths d accident record. Since then there was not much problems and the ınction operates satisfactorily at other times than peak periods [3]. The ılution devised was to introduce part-time traffic signal 25 metres back om the 'Give Way' line on all existing approaches to roundabout [4].

Data collection for both before and after situation has been carried ıt. These data include the traffic volumes and turning movements, time adway distributions of the circulatory flows, gap acceptance ıaracteristics, and accidents records.

Subsequently, statistical analysis on the obtained data were ıdertaken in order to assess the effectiveness of the entry signal control ıtroduction on the roundabout capacity and performance. Finally conclusion ›ints were arrived at coupled with recommendations for further relevant ›rk.

(2) DATA COLLECTION AND ABSTRACTION

Moors Street roundabout shown in Fig [1] is considered one of the ısiest intersections in the City of Sheffield (U.K). it deals with .000-5,500 vehicles during the peak hours [4]. Therefore it was decided to ırry out data collection proceduras required for 'before' and 'after' tudies . These data procedures were carried out using video tape recording ystem (V.T.R). A 'before' video tape of the roundabout had been taken in 984 during the evening peak hour on the 9th of April and during the ollowing morning peak hour on the 10th of April immediately before the ntroduction of the traffic signals. Three years later a similar video ecording for the 'after' situation was made in 1987 during also the vening and morning peaks of the 8th and the 9th of April. It should be entioned that on both 'before' and 'after' recordings , the time-base was uperimposed in such a manner to allow measuring the time length of any raffic event later on in the subsequent analysis of the filmed tapes in he traffic laboratory in Sheffield University.

The following types of measurements have been abstracted from the filmed tapes using direct playback of the video recordings onto a video monitor in the traffic laboratory.

(1) Measurements of traffic volumes and turning movements from all approaches to the roundabout under consideration.

(2) Measurements of the saturated entry flow, Q_e, on the Hanover Way, Ecclesall Road, and St. Mary's Gate approaches (i.e the flow entering the roundabout from each approach when there was a queue present in the approach) and of , Q_c, the corresponding circulatory flow (i.e the flow on the circulatory carriageway of the roundabout crossing the saturated entry flow).

(3) Measurements of gaps or time headways in the circulatory traffic stream across the Hanover Way and Ecclesall roads approaches and the number of entry vehicles accepting each gap length.

In order to measure the time headways in the circulatory traffic stream, a reference line was drawn on the video monitor in such a way that it cut across the circulatory carriageway in close proximity to the Hanover Way and Ecclesall road. Simply the difference between the superimposed times at which two consecutive circulating vehicles passed across the reference line represents the time headway. The time headway measurements were made over a period of 30 minutes on each of the two approaches (i.e Hanover Way and Ecclesall roads). Moreover the numbers of entry vehicles from the centre and offside lanes accepting each gap were also recorded.

(4) Accident record occurring at the roundabout or within 50 metres of its site was obtained for three years period 'before' and 'after' the installation of the traffic signal . It is noteworthy that at the end of the three years immediately following the installation of the traffic signal some road works of widening the carriageway of the remainder section of Hanover Way were in progress. In addition, some changes of the road users' habits were expected due to the implementation of the new signal scheme. Therefore it was decided to overlook the three years immediately after the installation of the traffic signal because of the above mentioned reasons.

Concerning the accidents record, the author contacted the local highway authority in the City of Sheffield and they provided him with the required accident information . From these accident data it was possible to classify the injury accidents occurred in three years time period representing the 'before' and 'after' situations. These three years were namely 1981,1982,and 1983 of the 'before' situation and 1987, 1988, and 1989 of the 'after' situation. Table (1) exhibits the accidents data obtained in terms of year and date of accident, accident severity (fatal, serious, or slight), location, description of each accident, and surface condition prevailing at the time of each accident.

(3) DATA ANALYSIS AND RESULTS

(3-1) Traffic Volumes and Turning Movements at Moore Street Roundabout

Since the cycle times for the morning and the evening peak hours in 'after' situation are 40 and 35 seconds respectively the counts of entry and circulatory flows were recorded continuously and then combined for successive 280 seconds intervals as an integral multiple of the cycle times for the sake of comparison. Vehicles were classified as 'light' (e.g passenger car or any other vehicle with not more than 4 tyres) or 'heavy' vehicle (e.g truck, or bus, or any other vehicle with more than 4 tyres). One 'light' vehicle is equivalent to one P.C.U whereas one 'heavy' vehicle is equivalent to two P.C.U's . These counts were made on lane by lane basis, and those resulting from unsaturated periods of lane flow were rejected. It is noteworthy that the turning movement volumes requires enormous amount of time for analysis, therefore only 5 minutes of observation time has been analysed and scaled up for the whole peak period. Fig (2) shows the traffic volumes at Moore Street roundabout during the morning peak hour for the 'before' and 'after' situations. Also, the approaches volumes of traffic and turning movements for the four periods of observation are summarised in Table (2). In addition, summary of the total traffic volumes entering the roundabout in both 'before' and 'after' situation are presented in Table (3)

(3-2) Entry and circulatory flows relationships

The analysis of the observed data concerning entry flows and the corresponding circulating flows was conducted for the above mentioned roundabout approaches, namely, Hanover Way, Ecclesall Road, and St. Mary's Gate for 'before' and 'after' situations. Firstly, the saturated 40-second and 35-second lane entry flows for morning and evening peak hours were respectively obtained. Each lane was considered saturated as long as continuous queueing existed. Secondly, these flows were summed up for the whole approach lanes for these fully saturated periods and plotted against the corresponding circulatory flows across the approach under consideration. The relationships between the entry flows and the circulatory flows during the morning peak periods for Ecclsall, St.Mary's, and Hanover Way approaches are shown in Fig.(3),(4),and Fig.(5) respectively.

In order to allow statistical comparisons to be made, mean values of the entry flows data and the corresponding circulatory flows data were calculated for each study period . Moreover regression lines for the 'before' and 'after' data passing through the respective means were drawn on the same graph, the slope of these regression lines being equal to that of the theoretical capacity line. In Appendix (A) the theoretical entry capacity equation used and an example of calculation for Ecclesall Road approach are given.

(3-3) Time Headways Distribution in the Circulatory Stream

As mentioned earlier in section (2), the time headways for circulating vehicles across Hanover Way and Ecclesall Road approaches were abstracted from the filmed tapes for a period of 30 minutes of observation. It should be mentioned that this measurement is a time consuming process. The time headway distribution for vehiclee in the circulatory stream across Hanover Way and Ecclesall roads are represented graphically by histograms shown in Fig (6) , and (7). For comparison purposes, for the 'before' and the 'after' situations the percentages of headways of specified sizes offered in the circulatory stream are represented for each case study. Also, for both of these two approaches the number of vehicles accepting different gap sizes offered in the circulatory stream are recorded on lane by lane basis. Table (4) gives these number obtained for Ecclesall Road approach.

3-4) Accident Data Analysis and Results

It is clear from Table(1) that, the number of accidents per year for the 'before' period are 4, 5, and 4 successively for year 1981, 1982, and 1983 and 6, 3, and 4 for the 'after' period of year 1987, 1988, and 1989 respectively. At glance, one can find that the total number of injury accidents for the 'before' and 'after' situations are equal. This means that there is no significant difference between both situations. Nevertheless, one can expect marginal decrease in the rate of accidents since the observed traffic volumes using the roundabout, being some 15% over the course of three years [2] (i.e from 1984 to 1987). However, from analysis of the accident by road user involved as given in Table (1), it is clear that the number of pedal cycles involved in accidents has increased from 2 to 5 from the 'before' to the 'after' situation. Also, the number of public service vehicles (P.S.V) involved in accidents has increased from 2 to 4 from the 'before' to the 'after' situation. In contrast to other forms of traffic signal control at intersections which in most cases result in reduction in number of injury accidents and number of collisions[6]. With regard to number of motor vehicles involved in accidents in both situations no significant difference has been detected.

4) Discussion of Results

(4-1) Traffic Volumes:- It can be seen from Table(3) that the total traffic volumes entering the roundabout have increased in both morning end evening peak periods in the course of three years from 1984 to 1987. Although the signalling scheme may not have directly contributed to the increase, however, the introduction of part-time entry traffic signal at the junction does prove its capability in handling such high volumes of traffic.

(4-2) Entry and Circulatory Flow:- Fig.(3), and (5) show that the entry capacity of Hanover Way and Ecclesall Road approaches corresponding to the mean of the circulating flows have increased by 30% and 12% respectively in the morning peak hour after the introduction of the part-time entry signals at the roundabout. As for St. Mary's Gate, it is clear from Fig.(4) that the entry flow has slightly decreaeed by 5% for all levels of flows during the morning peak hour. It should be mentioned that such decrease was expected because one of the purposes of installation of this traffic signal at the junction is to control the dominant flow from St. Mary's Gate and to provide more gaps in the circulatory stream for entering vehicles in the next two entries, namely, Ecclesall Road and Hanover Way.

Finally, it can be seen from Table(2) that in the morning peak periods the entry flowe from the Hanover Wey, Moore Street, and Ecclssall Road approaches have increased by 27% , 11% and 23% respectivsly whersas the entry flow from St. Mary's Gate approach has decreased slightly by only 5%. This gives an indication that the entry signal control et the junction has operated effectively in controlling the flows from the different epproachss. The entry flows from the approaches which previously experienced most delay, i.e the Hanover Way and Ecclesall Road approaches, has increased significantly. For the evening peak periods, the increases in entry flows are 25, 25, and 40 per cent for the Hanover Way, St. Mary's Gete and Ecclesall Road approaches whereas the decrease in entry flow is only 13 per cent for the Moore Street approach. This decrease is probably due to the high increase in entry flows from the previous two entries.

(4-3) Headway Distributions and Gap Acceptance Characteristics:- It is obvious from Fig.(6) and (7) that under the entry signal control scheme in the Moore Street roundabout the percentages of headways less then 0.5 second hava increased by 25% and 27% respectively for Hanover Way and Eccleeall Road during the morning peak periods. These increases are ascribed to the pletooning of the circulating vehicles which have been discharged from the previous entries under the signal control. In contrast, the percentages of headways in the range of 0.5 to 2.0 seconds have decreased by 10% for the circulating vehicles across Hanover Way and by 16% for the headways in the range of 0.5 to 1.5 second of the circulating vehicles across Ecclesall road. It is noteworthy that for Ecclesall Road high percentages of larger gaps were observed in the 'after' situation compared with those observed in the 'before' situation. This is apparent from Fig.(7). For headways of value in the range of 1.5 to 6.5 seconds, their percentages remained fairly constant in both 'before' and 'after' situations.

(5) Conclusion and Recommendations

As far as traffic signals at roundabouts are concerned the introduction of traffic signals has proved to be the most effective and economical solution for sharing out or balancing the entry flows between the approaches to roundabouts. On the other hand, they help coping with traffic arriving from adjacent signal-controlled intersections.

With regard to the 'before' and the 'after' studies carried out in this research work, the following points can be concluded:-

1- The traffic volumes entering the roundabout has increased by 17% and 6% in the evening and morning peak periods in the course of three years time from 1984 to 1987.

2- The introduction of the entry signal control has led to some 30% and 12% increase in the entry capacity in both peak periods from Hanover Way and Ecclesall Road approaches which had suffered great difficulties under the former offside priority operation.

3- The observed increase in capacity can be attributed to the platooning of circulating vehicles as a result of signal introduction. The queue acceptence phenomena frequently occurs after the signalling scheme has been implemented and this allows bunches of vehicles accept the large gaps offered in the circulatory flow [7].

In order to obtain an overall picture of the effectiveness of the entry signal control at such roundabouts, it is recommended to carry out measurements of vehicles delays and queue lengths on all approaches to the roundabout and compare the 'before' and 'after' situations. In fact, this will show to what extent the adopted solution is effective.

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Appendix (A)

The theoretical capacity equation used for tha calculation of the entr capacity of the approaches to roundabout under consideration is as follows:-

Calculation of the entry tapacity of the Ecclesall Road approach:-

Using the following equation, and the geometric parameters of the approach under consideration, one can proceed as follows :-

$Q_e = F\ (K - f_c Q_c)$ when $f_c Q_c \leq K$

$Q_e = 0$ When $f_c Q_c > K$

Where :-

$K = 1 - 0.00347(\phi - 30) - 0.978(1/r - 0.05)$

$F = 303\ x_2$

$f_c = 0.210\ t_D(1+0.2x\ )$

$t_D = 1+0.5/(1+M)$

$M = \exp\ [(D-60)/10]$

$x_2 = v+(e-v)/(1+2s)$

$s = 1.6\ (e - v)/L'$ = sharpness of flare

e = entry width (m)

v = approach half width (m)

L = average effective flare length (m)

D = inscribed circle diameter (m)

ϕ = entry angle (degree)

r = entry radius (m)

Q_e = entry capacity (p.c.u/hr)

Q_c = circulating flow (p.c.u/hr)

Substituting the geometric parameters of Ecclesall Road approach in the above equation, one can obtain the theoretical entry capacity line as given

$e = 15.0$ m
$v = 10.0$ m
$L' = 8.0$ m
$s = 1.6\ (e - v)/L' = 1.0$
$D = 78$ m
$\phi = 90^\circ\ \theta\ /2 = 90^\circ - 141^\circ\ /2 = 19.5$
$r = 56$ m
$x_2 = 11.667$
$M = 0.588$
$t = 1.315$
$f_c = 0.921$
$F = 3535$
$K = 1.068$

The theoretical entry capacity line equation will read the following form :-

$$Q_e = 3775 - 0.984\ Q_c$$

Fig (1)-General Layout of Moore Street Roundabout

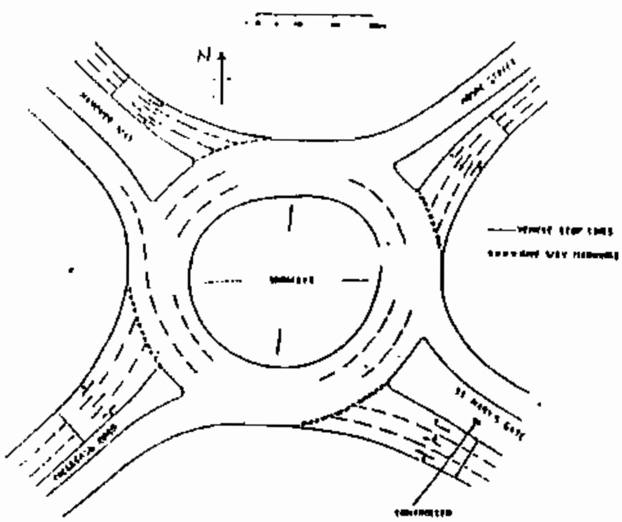
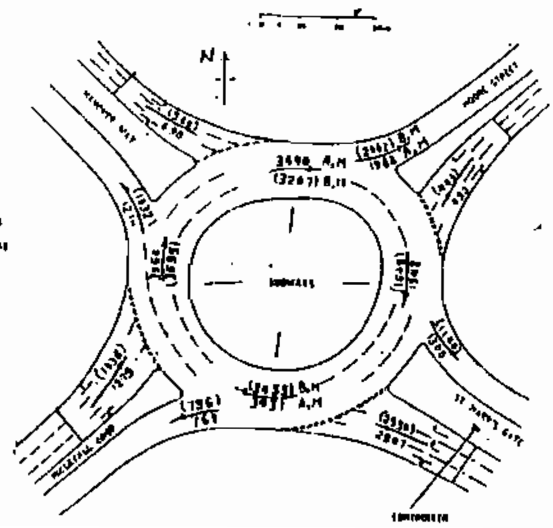


Fig.(2) Morning Peak Hour Traffic Volumes at Moore Street Roundabout.



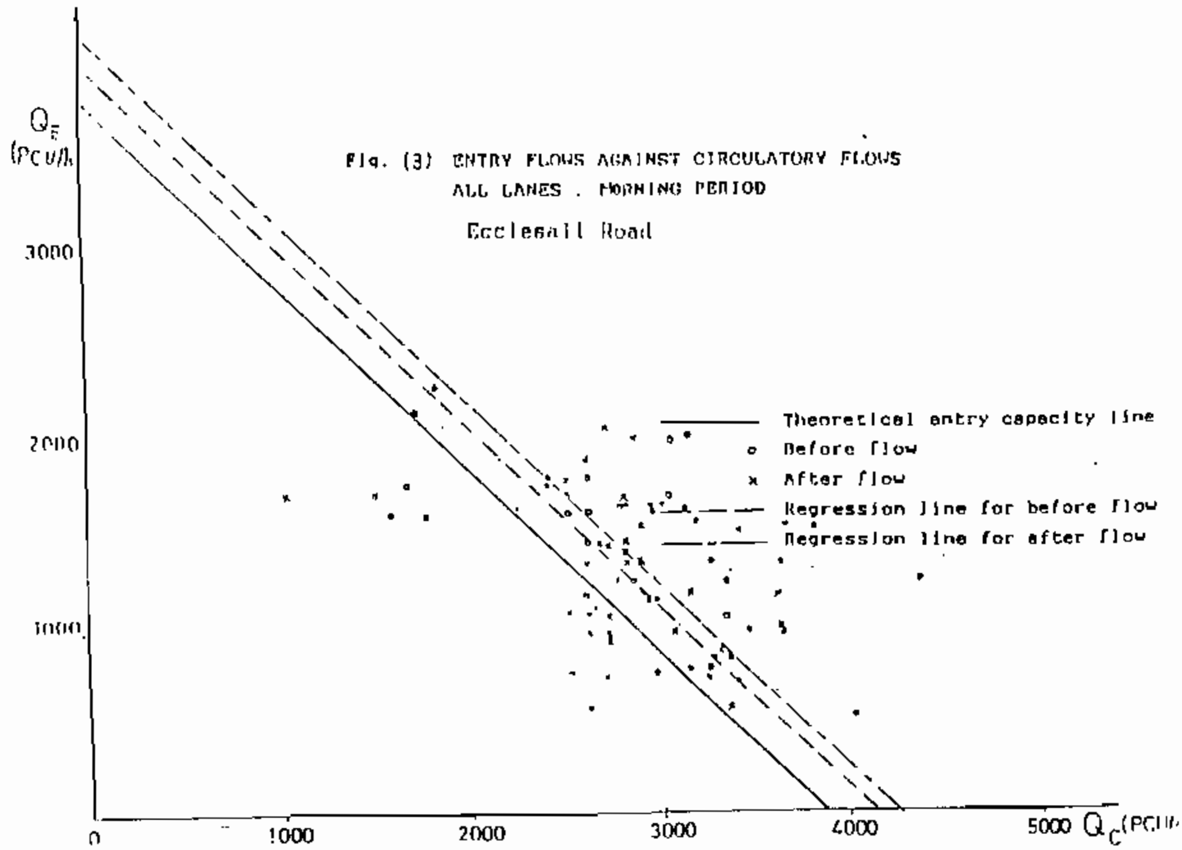


Fig. (3) ENTRY FLOWS AGAINST CIRCULATORY FLOWS
ALL LANES . MORNING PERIOD
Ecclesall Road
Q_E (PCU/h)
Q_C (PCU/h)
Theoretical entry capacity line
Before flow
After flow
Regression line for before flow
Regression line for after flow
0
1000
2000
3000
4000
5000

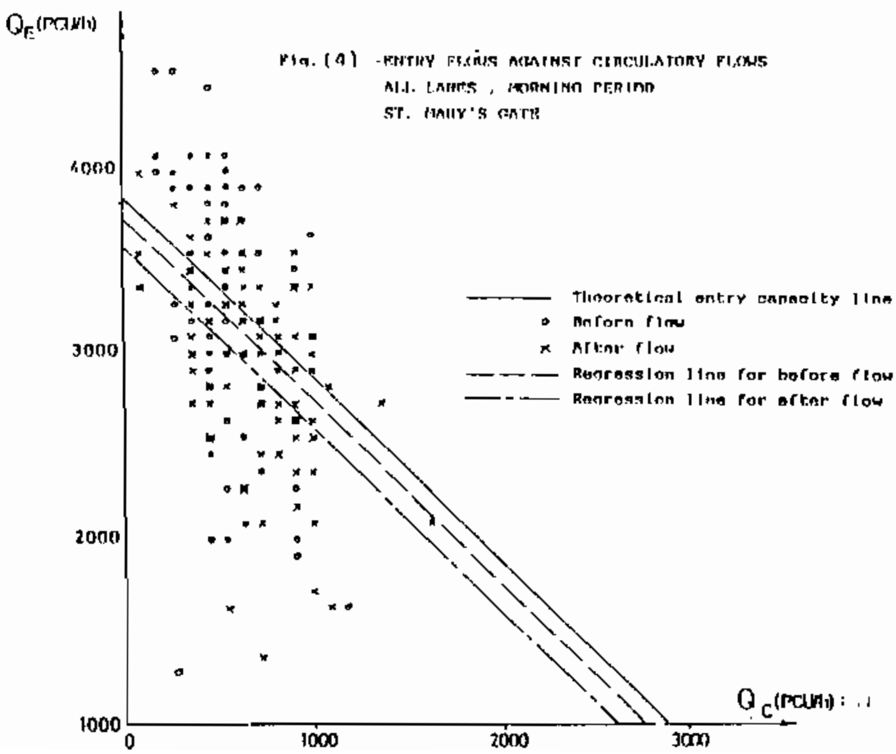


Fig. (4) ENTRY FLOWS AGAINST CIRCULATORY FLOWS
ALL LANES , MORNING PERIOD
ST. MARY'S GATE
Q_E (PCU/h)
Q_C (PCU/h)
Theoretical entry capacity line
Before flow
After flow
Regression line for before flow
Regression line for after flow
0
1000
2000
3000
4000

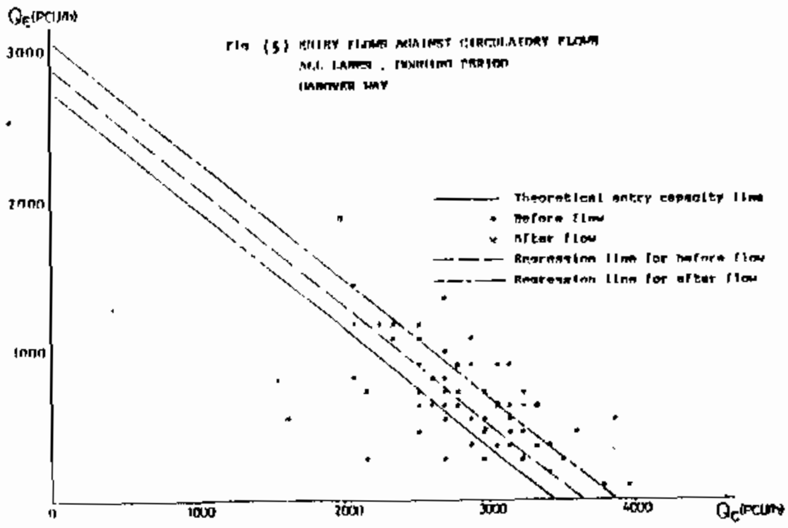


Fig (5) ENTRY FLOWS AGAINST CIRCULATORY FLOWS ALL LANES, MORNING PERIOD HANOVER WAY

Fig.(6) Time Headway Distribution for Circulatory Flow Across Hanover Way

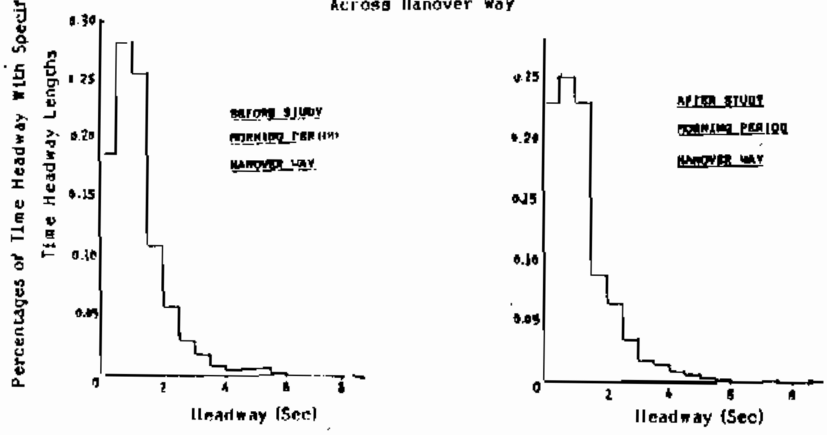


Fig (7) Time Headway Distribution for Circulatory Flow Across Ecclesall Road

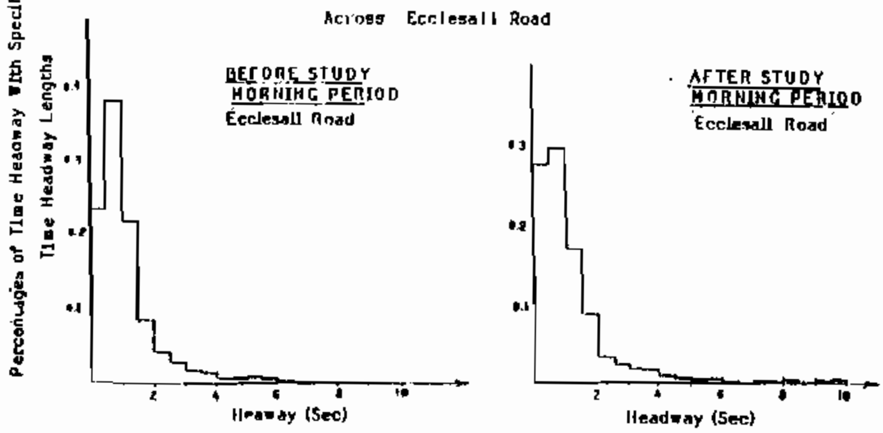


Table (1) Traffic Accident Data of 'Before' and 'After' Situations for Moore Street Roundabout.

Year	Date	Accident severity	Location of Accidents	Description	Surface Condition
1981	17/2	Slight	Hanover Way/Moore Street	PSV & G.Rail	Dry
1981	3/6	Slight	Moore Street/Clerence Street	PSV & Ped.	Dry
1981	8/8	Slight	Charles Row/Ecclesall Rd.	Veh & Veh	Wet
1981	3/9	Slight	St.Mary's Gate/Ecclesall Rd.	Veh & Ped.	Wet
1982	3/2	Slight	St. Mary's Gate/Ecclesall Rd	Ved$_1$ & Veh$_2$	Dry
1982	10/4	Slight	Moore Street/Ecclesall Rd.	Veh.& Median	Dry
1982	8/12	Slight	Hanover Way/ Ecclesall Rd.	Veh$_1$ & Veh$_2$	Wet
1982	11/12	Slight	Moore Street/St. Mary's Gate	Veh$_1$ & Veh$_2$	Wet
1982	29/12	Slight	Ecclesall Rd./St. Mary's Gate	Veh & G.rail	Dry
1983	24/4	Slight	Hanover Way/Moore Street	Veh$_1$&Veh$_2$&Veh$_3$	Dry
1983	31/7	Slight	Ecclesall Rd./Hanover Way	Veh$_1$&Veh$_2$	Dry
1983	19/11	Slight	Ecclesall Rd./Clarence Rd.	Veh$_1$&Veh$_2$	Dry
1983	29/11	Slight	Hanover Way/Ecclesall Rd.	Veh$_1$&Veh$_2$	Dry
1987	6/4	Slight	Hanover Way/ Ecclesall Rd.	Veh$_1$&Veh$_2$	Dry
1987	5/8	Slight	Ecclesall Rd./Hanover Way	Veh.&Cyclist	Dry
1987	14/9	Slight	Moore Street/Hanover Way	Veh.&Cyclist	Dry
1988	13/5	Slight	Moore Street/St. Mary's Gate	Veh.&Cyclist	Dry
1988	15/6	Slight	Moore Street/St. Mary's Gate	Veh.& C Res.	Dry
1988	31/8	Slight	St. Mary's Gate/Moore Street	Veh &Cyclist	Wet
1988	2/11	Slight	Hanover Way/Moore Street	chain of brakes	Wet
1988	4/11	Slight	Moore Street/St Mary's	Veh$_1$ & Veh$_2$	Snow
1988	22/11	Slight	Hanover Way/Moore Street	Veh$_1$&Veh$_2$ & rdt	Snow
1989	7/1	Slight	Moore Street/Hanover Way	Veh & P.S.V	Dry
1989	27/9	Slight	St.Mary's Gate/Ecclesall Rd.	Veh$_1$&Veh$_2$ & rdt	Wet
1989	3/10	Slight	Moore Street/Hanover Way	Veh. & P.S.V	Wet
1989	4/10	Slight	Hanover Way/ Moore Street	Veh$_1$&Veh$_2$ & rdt	Wet

Table (7) Summary of the turning movements and approaches traffic volumes at Moore Street Roundabout

Entry Approach	Peak Period	Turning Movements (Veh/hr)				Total Volume
		Left	Ahead	Right	U Turn	
HANOVER WAY	B.E	48	672	365	0	1085
	A.E	50	847	448	12	1357
	B.M	0	431	113	0	544
	A.M	54	460	176	0	690
MOORE STREET	B.E	293	786	106	23	1208
	A.E	210	656	154	28	1048
	B.M	54	311	43	32	440
	A.M	54	314	54	68	490
ST. MARY'S GATE	B.E	360	515	290	44	1209
	A.E	461	557	515	75	1608
	B.M	372	839	1415	324	2950
	A.M	262	1036	1233	276	2807
ECCLESALL ROAD	B.E	124	305	452	0	881
	A.E	132	542	536	20	1230
	B.M	150	755	131	0	1036
	A.M	124	633	510	12	1279

(A means after situation, B means before situation, M means morning peak hour, and E means evening peak hour.)

Table (8) Summary of total volumes entering the Moore Street roundabout

Peak Periods	Traffic Volumes
BEFORE , EVENING	4383 P.C.U/h
AFTER , ...	5243 ...
BEFORE , MORNING	4970 ...
AFTER , ...	5266 ...

Table (4) Gap Lengths and Number of Vehicles Accepting the Gaps from Each Lane of Ecclesall Road Approach in the 'before' and the 'After' Situations

Gap Length (Sec)	'Before' Situation			'After' Situation		
	Lane no. 1	Lane no. 2	Lane no. 3	Lane no. 1	Lane no. 2	Lane no. 3
0.5 - 1.0	0	0	0	0	1	0
1.0 - 1.5	5	1	0	0	0	0
1.5 - 2.0	14	6	1	10	1	4
2.0 - 2.5	6	6	2	3	3	2
2.5 - 3.0	23	17	7	12	10	5
3.0 - 3.5	20	34	22	15	14	14
3.5 - 4.0	16	20	15	21	14	13
4.0 - 4.5	17	19	11	11	14	7
4.5 - 5.0	13	18	13	11	15	14
5.0 - 5.5	10	18	17	16	16	17
5.5 - 6.0	16	23	17	19	30	29
6.0 - 6.5	8	13	12	11	9	9
6.5 - 7.0	3	2	2	7	7	7
7.0 - 7.5	0	5	3	0	0	0
7.5 - 8.0	1	2	2	0	6	6
8.0 - 8.5	2	3	3	10	10	9
8.5 - 9.0	0	0	0	4	4	4
9.0 - 9.5	0	0	0	16	14	14
> 10.0	9	9	9	39	50	49
Grand Total	516			636		