OPERATIONAL EFFICIENCY OF SIGNALIZED INTERSECTIONS IN AL-KHOBAR, SAUDI ARABIA

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الخلاصـــة :

معظم الإشارات الضوئية على التقاطعات في المملكة العربية السعودية تتحكم في حركة المركبات بإعطاء أحقية المرور لكلٍّ اتجاه على حدة . كما وإنَّ توقيت هذه الإشارات يَـتـمّ بطريقة التجربة والخطأ دون حُـسْبان مما يؤدي إلى حدوث مشاكل تشغيلية وبيئية وإحباطٍ للسائقين . إن هذا البحث يهدف أولاً إلى دراسة حجم هذه المشكلة ، وثانياً إلى تحليل خيارات بديلة لتوقيت وتصميم الإشارات الضوئية بغرض تطوير القدرة التشغيلية . ولإجراء هذه الدراسة تَـمَّ اختيار الإشارات الضوئية على تقاطـعْين لطرق رئيسية وتقاطعين آخرين مكونين من تقاطع طريق رئيسي بطريق فرعي ؛ وباستخدام برنامج المحاكاة (SOAP) تَـمَّ تحليل عدة خيارات لتصميم وتوقيت تلك الإشارات الضوئية على التقاطعات . وأخيراً تَـمَّ تحليل القدرة الاستيعابية لهذه التقاطعات بهدف مقارنة نوعية التشغيل لهذه التقاطعات عندما تعمل بخطة التوقيت الحالـيِّـة بنوعية التشغيل الناتجة عن تطبيق خطة التوقيت المقترحة من برنامج المحاكاة (SOAP) . وقد أظهرت هذه الدراسة أنَّ الخطة المقترحة من برنامج المحاكاة تؤدي إلى تحسن كبير في كمية التأخير الناتجة عن توقف المركبات وفي استهلاك الوقود إضافة إلى تحسن في القدرة على استيعاب المركبات الملتفة إلى اليسار وفي نوعية التشغيل . كما أظهرت الدراسة أن استخدام هذه الخطة المقترحة يمكن أن يوفر في المصاريف التشغيلية ما مقداره ثمانية ملايين ريال سعودي سنوياً إضافة إلى توفير في وقت السائقين بما يوازي (٨٠) مليون ريال سعودي سنوياً .

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ABSTRACT

Almost all signalized intersections in Saudi Arabia are operated with total directional separation, *i.e.*, by allowing a separate phase for each direction. Furthermore, the signal splits are adjusted on a trial-and-error basis without any calculations. This causes many operational and environmental problems and driver frustration.

This study aims, first, to investigate the extent of the problem and, second, to analyze alternative phasing and signal characteristics for the purpose of operational improvements.

Two signalized intersections on crossings of a major arterial by a major arterial and two on a major arterial by a collector street were selected for the purposes of this study. Existing signalization and various signal alternatives were analyzed using a signal optimization and simulation package (SOAP). Finally, capacity analyses were performed to establish and compare the levels of service of the existing signalization and the best signal phasing scheme which was selected by SOAP.

Study showed that considerable improvements in stopped delays, excess fuel consumption, excess left-turning vehicles, and levels of service could be achieved through signal optimization. In the study area alone, SR 8 million/year for vehicle operating costs and SR 50 million/year of time savings could be realized simply by signal optimization.

OPERATIONAL EFFICIENCY OF SIGNALIZED INTERSECTIONS IN AL-KHOBAR, SAUDI ARABIA

INTRODUCTION

Almost all signalized intersections in Saudi Arabia are operated with total directional separation, *i.e.*, by allowing a separate phase for each direction. Furthermore, the signal splits for most of these intersections are adjusted on a trial-and-error basis, without any calculations which takes the intersection and traffic characteristics into account. This causes many operational and environmental problems such as delays, increased fuel consumption, accidents, driver frustration, and increased levels of air pollution.

This study aims, first, to investigate the extent of the problem by detailed studies at some major arterial intersections and, second, to analyze alternative phasing and signal characteristics for the purposes of operational improvements.

Two intersections on crossings of major arterial by major arterial and two intersections on major arterial by collector streets were selected for the purposes of this study. The data for the four intersections were obtained from a previous research study [1], which included traffic volumes for morning and afternoon peak periods and all the layout and signal characteristics. Optimum timings and various measures of effectiveness were obtained using a signal optimization package, SOAP [2], for various phasing schemes. Measures of effectiveness (MOE) included delay, stops, excess fuel, excess left turn, maximum queue lengths, and volume capacity ratio. The optimization package was also used to simulate the existing conditions imposing the signal phasing. Finally, the highway capacity software (HCS) [3] was applied to find and compare the levels of services of the best signal phasing scheme and the existing signalization for the intersections.

BACKGROUND

Development of optimal timing plans for signalized intersections is a major task for traffic engineers. In the 1950s computers were first recognized and introduced as possible tools for studying and analyzing traffic problems. Since that time considerable effort has been put into developing computer programs to aid in the operational design of traffic signal systems.

SOAP (Signal Operation Analysis Package) [2] is one of a number of computer programs available to assist in the operational design of traffic signal systems. The program is intended to be used in the analysis of design alternatives for four-legged isolated intersections. As such, SOAP has a limited application when compared to the well-known state-of-the-art TRANSYT (*TRA*ffic *N*etwork *S*tud*Y* *T*ool) [4] program which is used for simulation and optimization of isolated intersections, arterial roads, and grid networks. Nevertheless, SOAP is far simpler than TRANSYT and requires less training and input data. These characteristics were actually design criteria in the development of SOAP. This does not mean that SOAP lacks efficiency or accuracy in handling four-legged isolated intersections. In fact, the computational methodology of SOAP and the state-of-the-art TRANSYT program is very similar. For example, the determination of delay, which is the main ingredient in any traffic model, in SOAP and TRANSYT is based on a modified version of the Webster model [5]. Hagen and Courage [6] compared the HCS delay computations with the corresponding computations performed by SOAP and TRANSYT and found that all of the models agree closely at volume levels below the saturation point. Similarly, the objective functions to be minimized in SOAP and TRANSYT are a very comparable weighted sum of delay and stop.

The delay model used in SOAP is based on the assumption of independent, isolated operation. In other words, it is assumed that the arrival patterns are not influenced by the operation of the nearby signals. The SOAP model assumes that while a stochastic variation may occur from cycle to cycle, the distribution of arrivals is uniform with respect to any particular cycle. For isolated signalized intersection operation the TRANSYT model has similar assumptions for arrival patterns and because the same delay formula is used in the computation of delays in both models, it is expected, and indeed shown [6], to produce similar results. Therefore, if the intersections are assumed to operate independently of other intersections, the SOAP model seems to be a better choice because of its simplicity. Currently signal coordination is applied at a very few arterials in the Al-Khobar area, with some limited success, mainly because of some hardware problems related to setting up the signal offsets and the long distances between the signalized intersections. Therefore the assumption of "isolated intersections" for the majority of signalized intersections will not be too unrealistic for the area of the study. Furthermore, as explained above, it was shown [9] that the SOAP package could reasonably simulate the intersection delays in the same study area with the isolated operation assumption.

The calculation of stops and fuel consumption, which is another crucial computation in any traffic model, is sufficiently accurate. It has been reported [2] that the results of the application of a state-of-the-art simulation model, NETSIM (Network Simulation) [7] were substantially in agreement with the result obtained with SOAP. Currently, SOAP is used by over 200 cities, states, and consultants throughout the United States [8]. A previous study [9] indicated that SOAP simulates the MOE's reasonably well for the local conditions. In this study, which used the same study area with this study, a correlation coefficient of 0.924 was obtained between the actual delays and delays simulated with SOAP.

In summary, SOAP was chosen for this study because it is accurate, very user friendly, and valid for local conditions. As the major goal of this study is to encourage traffic engineers in Saudi Arabia to utilize computerized traffic programs which have proved to be valid for local conditions, these are very important characteristics. Thus SOAP should constitute an excellent start for local traffic engineers.

The Highway Capacity manual [10] and its software, which is well known to most traffic engineers, was used to further evaluate the improvements in traffic operation as a result of using signal timing plans obtained by SOAP.

DATA

Data needed for this work was obtained from a previous research study [1]. Table 1 shows the geometric characteristics and traffic volumes for the selected intersections. All of the selected intersections were located in Al-Khobar, which is a city in the Eastern coast of Saudi Arabia, all were on major arterial streets with medians and all were four-legged intersections. Volume counts consisted of four 20-minute periods in the morning peak times and four 20-minute periods in the afternoon peak times, *i.e.*, a total study period of 2 hours 40 minutes was used in the research.

Table 1. Intersection Characteristics and Volumes.

Intersection Type	Intersection	Approach (Bound)	Approach width, m (Including left turn lanes)	Number of Lanes for		Traffic Volumes					
						Morning peak			Afternoon Peak		
				Thru & Right	Left Turn	Left	Turn	Right	Left	Turn	Right
Major by Major	K. Abdulaziz by 28th Street	N	18	4	1	225	712	127	292	682	201
		S	27.5	5	2	389	454	65	661	858	146
		E	11	2	1	232	172	28	195	339	69
		W	10.5	2	1	145	216	160	209	290	96
	Dhahran Road by Aziziyah Street	N	10.5	3	0	261	431	290	148	523	329
		S	10.5	3	0	105	273	27	314	461	42
		E	18.5	4	2	419	524	141	411	801	157
		W	18.5	4	2	251	305	126	630	835	247
Major by Collector	K. Abdulaziz by 22nd Street	N	18.2	4	1	68	761	24	159	924	43
		S	18.2	4	1	68	380	14	140	1101	50
		E	6.0	2	0	57	35	26	82	118	40
		W	6.0	2	0	18	45	33	71	74	20
	Makkah Street by 20th Street	N	10.3	3	0	56	231	30	130	436	51
		S	10.3	3	0	96	189	27	155	356	77
		E	10.3	3	0	140	123	21	164	203	65
		W	10.3	3	0	48	68	77	122	172	100

The phasing terminology used in the study is shown in Table 2. Most of the intersections in Saudi Arabia are operated using the first phasing design scheme and permissive left turns are not employed. Three other feasible alternatives which do not allow permissive left turns were added for testing in this study.

ANALYSIS OF SIGNAL OPTIMIZATION

The signal operations analysis package SOAP was applied to obtain the optimal signal settings, to simulate the conditions for the existing signal timings and to obtain the associated measures of effectiveness resulting from these operating conditions. All SOAP runs were specified to have two dials (control programs), one for the morning peak period and one for the afternoon peak period. The MOE's resulting from optimum timings for four different phasing alternatives and the existing conditions are given in Table 3.

The savings in delay (vehicle hours) compared to existing signalization were 19.0% and 6.5% for intersections 1 and 2 respectively. These intersections were located on the crossing of a major by major arterial. Both of these intersections were very heavily trafficked intersections working at their capacities during peak periods. The total potential savings for these two intersections was 34.28 vehicle-hours for the total study duration of 2 hours 40 minutes. More reductions in delay can be made in the second category of intersections on major arterials by collector streets. Delays can be reduced by 34% and 24% on intersections 3 and 4 resulting in a total savings of 26 vehicle-hours for the total study duration.

The total stopping delay for these four intersections in a 2 h 40 min study period was 67.89 hours. Approximately ⅛th of total average daily traffic (ADT) occurs during this period and assuming that there are 100 such signalized intersections in Al-Khobar and its sister cities Dammam and Dhahran which are now physically united to form a larger metropolitan area, this results in a total yearly delay of:

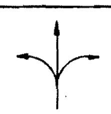
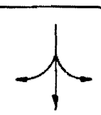
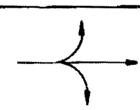
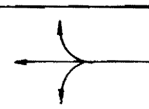
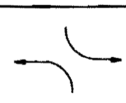
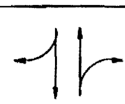
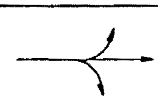
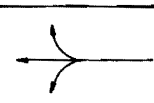
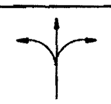
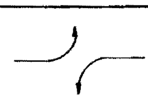
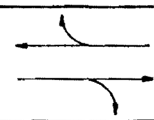
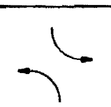
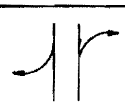
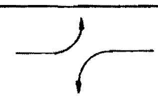
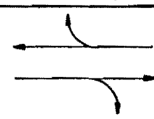
$$67.89 \times 8 \times 365 \times \frac{100}{4} = 4\,955\,970 \text{ hrs.}$$

Idling cost for passenger cars with 1975 prices is $313 per 1000 hours [10]. Assuming an inflation rate of 2% this is equivalent to $430 per 1000 hours in 1991 values. Therefore the approximate savings that could be achieved from the optimization of signals in the Al-Khobar–Dammam–Dhahran metropolitan area is:

$$(\text{SR } 3.75/\text{US\$}) \times 0.430 \text{ US\$/hr} \times 4\,955\,970 = \text{SR } 7\,991\,501 \text{ per year.}$$

So a saving of approximately SR 8 million/year could, in theory, be realized simply by optimizing the

Table 2. Signal Phasing Terminology.

Phasing Design		Phases			
No.	Code	A	B	C	D
1	N S E W				
2	L T E W				
3	N S L T				
4	L T L T				

signalized intersections. It should be noted that this saving represents only vehicle operating costs such as fuel, oil, tire maintenance, *etc.* and does not reflect time savings. If one assumes an average value of time of 10 SR/hr (An average value of US $3 per hour (1975 values) is suggested by AASHTO [11]) this would mean further savings of SR 50 000 000 per year.

No significant savings in the percentages of vehicles stopped were achieved. A marginal saving was achieved at intersections 3, almost equal performances were obtained in intersections 1 and 4, and existing phasing scored marginally better at intersection 2.

Savings in excess fuel (expressed in gallons) seem possible. Since the excess fuel is computed as the sum of two linear functions of stops and delays in SOAP and since there were considerable savings in delays this could be expected. In this MOE, savings of 7.8, 2.4, 12.0, and 8.2 percent can be achieved for intersections 1, 2, 3, and 4 respectively, representing a total fuel saving of 41.37 gallons for the study period of 2 hours 40 minutes.

The excess left turning vehicles which a particular operation is unable to accommodate, either on protected turning intervals, or through natural gaps in the oncoming traffic, is used in identifying problems related to left turns.

> "The rationale behind this definition is simply that left turns which cannot be accommodated safely tend to discharge themselves with a greater degree of risk through the last few seconds of the clearance interval (or perhaps the first few second of the red)." ([2]. p. B-18).

In terms of this MOE, the existing phasing scheme for intersections on major arterials by major arterials (*i.e.* intersections 1 and 2) performs rather poorly. With signal optimization the excess left turns can

Table 3. Measures of Effectiveness.

Type of Intersection	Intersection	Phasing Alternatives	Delay (Veh.-Hrs)	Stops (%)	Excess Fuel (Gal)	Excess Left Turns (Vehicles)	Max Queue Length (Vehicles)	Max V/C Ratio	Comments
Major Arterial By Major Arterial	K. Abdulaziz by 28th Street	1. NS EW	103.34	92.1	144.71	21	27.5	1.09	
		2. LT EW	99.55	94.6	144.73	3	26.5	1.01	BEST
		3. NS LT	105.19	91.9	145.69	12	28.5	1.07	
		4. LT LT	102.27	94.0	145.85	1	29.1	1.00	
		Existing (NS EW)	124.07	91.8	156.97	104	33.3	1.21	
	Dhahran Road by Aziziyah Street	1. NS EW	100.18	94.0	130.81	16	36.9	1.06	BEST
		2. LT EW	102.50	94.6	132.62	16	36.9	1.06	
		3. NS LT	102.96	94.8	133.07	29	39.6	1.07	
		4. LT LT	104.34	95.3	134.26	35	39.6	1.09	
		Existing (NS LT)	109.74	90.6	133.98	176	34.5	1.51	
Major Arterial By Collector Street	K. Abdulaziz by 22nd Street	1. NS EW	57.00	90.2	87.43	0	31.2	0.80	
		2. LT EW	49.84	80.6	77.47	0	28.2	0.96	BEST
		3. NS LT	57.00	90.2	87.43	0	31.2	0.80	
		4. LT LT	49.84	80.6	77.47	0	28.2	0.96	BEST
		Existing (NS EW)	75.56	91.6	99.35	0	41.3	0.94	
	Makkah Street by 20th Street	1. NS EW	25.62	90.6	46.92	0	9.0	0.76	
		2. LT EW	24.24	90.5	46.07	0	8.4	0.86	
		3. NS LT	24.53	91.0	46.39	0	8.4	0.81	
		4. LT LT	23.08	90.5	45.38	0	7.6	0.89	BEST
		Existing (NS EW)	30.54	89.4	49.46	0	11.5	0.80	

almost be totally eliminated from these intersections, reducing the possibility of accidents involving left turning vehicles. At the second group of intersections (*i.e.* intersections 3 and 4), sufficient left-turning capacities and smaller volumes resulted in no excess left turns. Apparently signal optimization becomes most beneficial in reducing and almost eliminating excess left turns at high-volume intersections, and hence reducing the possibility of accidents.

Maximum queue lengths (which is the longest of all queues occurring at all approaches during all time intervals) did not show any important differences for major by major intersections but some reductions were made on major by collector intersections. In the first group of intersections, a reduction of 20% was achieved in intersection 1 and an increase of 7% was obtained in intersection 2. Reductions of 32% and 34% were achieved in this MOE for intersections 3 and 4. It may therefore be said that optimization becomes more important in reducing queues in intersections where capacities have not yet been reached.

The maximum volume capacity ratio given in Table 3 is the highest of all the study periods (in this study eight twenty-minute periods). Since optimization considers all the intervals and not just one interval, interpretation based on a single interval should be made with caution. However, from a study of this MOE it can be said that improvements are certainly possible. This MOE significantly affects levels of service and the highway capacity analysis presented below supports this observation.

It should be noted that delay could be considered as the most important MOE because it is also a proxy for the remaining MOE's. Therefore selection of the "best" phasing sequence was based upon this MOE alone. However, it should be noted that the "best" phasing sequence so selected is at the same time best for most of the other MOE's.

At all intersections except intersection 2, which is operating at levels exceeding its capacity, a phasing involving at least one set of (LT) sequences was selected as the best. Although more studies, perhaps with more intersections, are needed, this study shows that phasing sequences involving left turns alone (L) and through and right turning movements (T) in one or two directions may be better than the more common phasing of providing one phase for each approach (NSEW) at least for intersections working below their capacities.

Comparisons of signal timing designs for the best phasing sequence and the existing situation are presented in Table 4. It can be seen that in three out of four intersections, existing signal phasing was obtained by simply dividing the available time by four (number of phases). Considering the imbalances between the number of lanes, traffic volumes *etc.*, this seems illogical. Again, cycle lengths which are much longer than needed were used. Since longer cycle lengths result in larger delays, this is not a good practice. In three out of four intersections, an unwarranted cycle length of 120 seconds was used. In the fourth intersection, where a 90 s cycle was used, a 55–60 s cycle would have been quite sufficient.

Table 4. Comparison of Signal Timing.

Intersection	Case	Sequence	Signal Timing: Morning Peak: Cycle (sec)	Morning Peak % of Split PH.1	PH.2	PH.3	PH.4	Afternoon Peak: Cycle (sec)	Afternoon Peak % of Split PH.1	PH.2	PH.3	PH.4
K. Abdulaziz & 28th Street	Best	LT EW	90	24.7	20.5	24.8	21.1	90	28.3	19.5	22.2	21.1
	Existing	NS EW	120	23.3	23.3	23.3	23.3	120	23.3	23.3	23.3	23.3
Dhahran Road & Aziziyah Street	Best	NS EW	80	24.0	18.8	26.0	18.8	120	19.3	26.5	19.3	26.6
	Existing	NS LT	120	19.2	19.2	23.3	31.7	120	19.2	19.2	23.3	31.7
K. Abdulaziz & 22nd Street	Best	LTEW (LTLT)	105	11.9	44.3	18.1	18.1	95	16.5	35.1	20.0	20.0
	Existing	NS EW	120	23.3	23.3	23.3	23.3	120	23.3	23.3	23.3	23.3
Makkah Street & 20th Street	Best	LT LT	55	18.3	27.3	23.6	27.3	55	20.6	27.3	21.2	27.3
	Existing	NS EW	90	23.3	23.3	23.3	23.3	90	23.3	23.3	23.3	23.3

Another point to be noted is that the same signal splits were used in the morning and afternoon periods. Again this is illogical because there are directional imbalances between morning and afternoon peaks, as can be observed in Table 1.

CAPACITY ANALYSIS

Using the Highway Capacity Software [3], capacity analyses were performed for the best signalization alternative obtained by SOAP and the existing situation for the afternoon peak hour volumes. The results of this analysis are presented in Table 5. The levels of service (LOS) were calculated using the procedures explained in the Highway Capacity Manual [10] and is based upon the stopped delay per vehicle. LOS's are categorized on A, B, C, D, E, and F; A being the best with delays less than 5 seconds/vehicle and F being the worst, describing operations with delays in excess of 60 seconds/vehicle which occur when arrival flow rates exceed the capacity of the intersection. However, it is possible to have delays in the range of LOS F while the v/c ratio is below 1.00. This situation occurs:

> "When some combination of the following conditions exists: (1) the cycle length is long, (2) the lane group in question is disadvantaged (has a long red time) by the signal timing, and/or (3) the signal progression for the subject movements is poor." ([10], p.9-5).

Table 5 clearly indicates that improvements in LOS's are possible in all the intersections and levels of service can be improved at least to one higher level with signal optimization. These improvements are the result of shorter cycle lengths and balanced signal splits, which shorten the stopped delays per vehicle.

SUMMARY AND CONCLUSIONS

The summary of the main research findings are listed below.

1. All of the studied signalized intersections have long cycle lengths which are unwarranted as shown. Three out of four of these have signal splits which are obtained simply by equally distributing the available time between all phases. Furthermore, the same phase splits and cycle lengths were employed both in the morning peak and afternoon peak periods. It appears obvious that even cursory calculations for the selection of optimum signal cycle and signal splits did not take place.

2. Considerable reductions in the most important MOE, namely delay, were possible for all four of the studied intersections. Relatively higher reductions (around 25−35%) in the extent of delay are possible at intersections which are operating below their capacities as compared to intersections which are operating close to their capacities, where reductions of around 5−20% were shown to be possible. With approximate calculations, this indicates a saving of 5 million hours/year in the Al-Khobar, Dammam, Dhahran metropolitan area. In monetary values this means an approximate saving of SR 8 million/year for vehicle operating costs and further savings of SR 50 million/

Table 5. Level of Service Comparison.

Intersection	Case	Sequences	Level of Services in the Peak Hour				
			North Bound	South Bound	East Bound	West Bound	Overall LOS
K. Abdulaziz &	Best	LT EW	C	C	D	D	D
28th Street	Existing	NS EW	D	F	D	D	E
Dhahran Road &	Best	NS EW	D	F	D	D	E
Aziziyah Street	Existing	NS LT	*	*	C	F	*
K. Abdulaziz &	Best	LTEW (LTLT)	B	B	C	C	B
22nd Street	Existing	NS EW	D	E	D	D	D
Makkah Street &	Best	LT LT	C	C	C	B	C
20th Street	Existing	NS EW	D	D	D	D	D

*Reasonable delay estimates cannot be made because of v/c ratios exceeding 1.

year for time savings (assuming a time value of SR 10/h).

3. For the intersections studied, signal optimization does not seem to significantly affect the percentage of stopping vehicles.

4. Considerable fuel savings can be achieved in all four intersections. This saving is reflected in the total idling cost mentioned in 2 above.

5. Excess left turning vehicles can be almost totally eliminated from heavily trafficked intersections by signal optimization, reducing the possibility of accidents involving left-turning vehicles.

6. Maximum queue lengths did not show any important differences for major by major arterials, but some reductions are possible on major by collector street intersections. Reductions of around 30–35% were achieved for this MOE for the latter category of intersections.

7. There are some indications that phasing sequences involving separate phases for left-turns alone (L) and through and right turns alone (T) in one or two directions (such as LT EN, NS LT, or LT LT) may be better than the more common phasing of providing one phase for each approach (NSEW), at least for intersections working below their capacities. However, this finding needs to be validated with further studies.

8. Capacity analysis indicated that improvements in LOS's were possible for all the studied intersections. LOS's were improved at least to one level above with signal optimization in all intersections.

9. One final comment relates to the safety and movement of pedestrians at signalized intersections. Unidirectional signal operations (NSEW) lacks safe pedestrian crossing times unless there is a substantial all-red phase. Al-Senan *et al.* [12] showed that a pedestrian has to wait 1 min 30 sec and 2 min 15 sec for 120 and 180 sec cycles respectively to make a legal crossing on a signalized intersection approach with median. These waiting times will be doubled if the pedestrian has to cross two approaches. In this same study it was also reported that, most likely because of these long waiting times, 56 percent of male pedestrians and 32 percent of females cross signalized intersections in the prohibited phase. Obviously the NSEW phasing alternative is not a good one from the pedestrian point of view either.

RECOMMENDATIONS

The practical implications of the study and further recommendations are listed below.

1. Signal optimization with a relatively easy to use computer program like SOAP should lead to considerable improvements. Therefore the traffic organizations are urged to use these programs.

2. Further research is needed to establish the best phasing patterns (some of which are presented in Table 2).

3. This study analyzed the intersections as isolated intersections. It is believed that further improvements could be achieved by signal coordination. These potential improvements should be investigated.

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