SIGNAL COORDINATION OF TRAFFIC SIGNALS ON ELJALAA ARTERIAL, GAZA USING TRANSYT-7F

تنسيق وتصميم الإشارات الضوئية على شارع الجلاء في غزة بواسطة TRANSYT-7F

Essam H. Almasri
Civil Engineering Department
Islamic University, Gaza
P.O Box 108, Gaza, Palestine
Email: emasry@iugaza.mail.edu.ps

ملخص البحث

تهدف هذه الدراسة إلى إعادة التصميم والتنسيق بين الإشارات الضوئية الواقعة على طول شارع الجلاء الذي يقع في مدينة غزة، ثم تقوم بمقارنة هذا التصميم مع الوضع الحالي للإشارات الغير منسقة، يتم ذلك باستخدام TRANSYT-7F وهو أحد البرامج الأكثر استخداما في التنسيق بين الإشارات الضوئية، واستند التحليل والتصميم على البيانات الهندسية التي جمعت والعد المروري الذي تم في تاريخ ٢١/١/٢٠٠٧ في فترة الذروة المسائية، النتائج أظهرت أنه بعد التصميم والتنسيق بين الإشارات الضوئية تم انخفاض في قيم زمن النقل والتأخير و التوقف و استهلاك الوقود بنسبة ٣١% و٤٦% و٢٣% و٢٢% على التوالي، وقد تحسن مستوى الخدمة من مستوى E إلى مستوى D، لذلك يوصى بالقيام بالتنسيق بين الإشارات الضوئية في كل الشوارع الرئيسية في مدينة غزة.

Abstract

This study aims to redesign and coordinate the traffic signals along Eljalaa arterial located in Gaza city and to compare them with existing uncoordinated signals using TRANSYT-7F which is one of the most widely used signal coordination programs. The analysis and design are based on geometric data and manual traffic count carried out on Sunday 21/10/2007 in the evening peak period. The results show that after coordinating a reduction of travel time, delay, stops and fuel consumption by 31%, 46%, 23% and 22% respectively. The level of service has been improved from E to D. Thus, it is recommended that signal coordination should be carried out at all arterials in Gaza.

Key Words: Congestion; Signal Coordination; TRANSYT-7F; Delay

1 Introduction

Gaza Strip is the southern part of the Palestinian Territories and is composed of five governorates namely, Gaza, Khan-Younis, Rafah, and Middle and North Governorates. Gaza Strip has an area of 365 km^2 and it is a narrow coastal strip of land with a length of 40km along the Mediterranean Sea in the northwest direction. It has 58 km borders with An-Naqav Desert to the east and south and 12 km with Egypt to the southwest. It takes its name from its main city Gaza.

Today transportation system in Gaza Strip consists only of road transport. The Gaza strip has a small, poorly developed road network. The road network consists of

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61 km of main roads, 57.8 km of regional roads and 511 km of local road [1]. There was a single railway line running from north to south along its center. Nowadays it is deserted and in disrepair, and little trackage remains. Gaza strip had a small airport to the east of Rafah Governorate; however, it was totally destroyed by the occupation several years ago. At the start of the Palestinian Authority, a small harbor has been built which is only used by fishermen. Since the time of building of this harbor it was not allowed for foreign ships to dock at the harbor.

Most official and non-official organizations are located in Gaza city and concentrated in the middle part resulting in serious traffic congestion especially in major roads like Eljalaa Road. This road is a major arterial connecting the southern part of Gaza city with the northern part. The congestion appears clearly in the segment which consists of 5 consecutive signalized intersections.

What makes the congestion worse is the not-efficient traffic signal control; where each intersection is treated in isolation. Furthermore, the timing setting is normally developed without proper calculations; but, it is usually assigned using experience which is not always the optimum solution. The key solution to this congestion problem is to arrange the green signal at the downstream signalized intersection to match with the platoon traffic flow arriving from the upstream signalized intersection. This arrangement is called signal coordination.

Given this context, this study aims at analyzing the existing traffic situation of the five consecutive uncoordinated signalized intersections located along Eljalaa Road. This study is intended to redesign the timing settings of these signalized intersections such that the signals are coordinated. The results of this study can improve the level of service of Eljalaa arterial; decrease delay; reduce vehicle emissions and fuel consumption; reduce driver aggravation related to unnecessary stops that may cause accidents; and enable traffic signals to communicate with each other allowing them to work together.

What follows this section is a general background on signal control and coordination. Then, the paper proceeds to a description of the selected signal coordination methodology. Section 4 presents data collection. Section 5 provides the results of traffic situation analysis and signal coordination. Finally, section 6 concludes major findings and recommendations.

2 Background

2.1 Definitions

An intersection is defined as an area shared by two or more roadways. Its main role is to allow the change of route directions. Intersections can be classified as grade-separated or at-grade [2]. Traffic control is used to allocate the right of way to drivers and thus to improve highway safety by ensuring the orderly and predictable movement of all traffic on highways. Traffic control devices are signs, signals, or markings which are used to regulate, guide, and/or warn traffic [3].

Traffic signal is considered to be one of the most effective methods of intersection traffic control. It allows vehicle movements to be controlled by assigning time intervals. Traffic signal is frequently adopted at busy urban intersection. It can result in reducing congestion and improving road safety [4].

2.2 Types of Signal Control

Traffic signals may operate independently, or as a system, thus, traffic control can be scaled into three categories which are individual intersection control, arterial control, and network control. In individual intersection control, a single traffic signal operates in a pre-timed, actuated, or traffic responsive mode, without affecting the operation of other traffic signals. In arterial control, two or more traffic signals operate synchronously along an arterial street in a pre-timed progression, traffic responsive, or adaptive control mode. In network control, traffic signals throughout an entire network of intersections are coordinated through a timing plan created offline, or an adaptive control strategy [5].

Individual intersection control is already used in Gaza and has proved to be not efficient as drivers have to stop at each intersection along arterials like Eljalaa arterial. Because the studied intersections are located consecutive along Eljalaa road, the arterial control is adopted in this study. Traffic responsive or adaptive control mode requires the installation of traffic detectors at intersections which are expensive and not affordable by the responsible authorities in Gaza because of the bad economical situation. Therefore, the pre-timed progression (fixed time control) will be assumed in this study.

Fixed time control is the most widely used form of signal control. In fixed time control, signals are controlled using fixed timing plans. There are usually several coordination timing plans that are put into operation on a 'time of day, day of week' schedule. The plans consist of splits, cycle lengths, and offsets for every signalized intersection. These plans are developed offline either using manual methods or using special software and then loaded onto the controller [6].

2.3 Signal Control Software

There are different software packages for fixed time control such as TRANSYT-7F [7], SOAP [8], MAXBAND [9], PASSER II [10], PASSER III [11], PASSER IV [12], and SIGOP III [13]. Among these software packages, TRANSYT-7F is selected in this study as it is one of the most widely used signal coordination programs [14], [15], [16]). TRANSYT-7F is a version based on TRANSYT (Robertson [17]) and is modified specifically for the United States. TRANSYT was originally developed by the Transportation and Road Research Laboratory in England in 1968. Other reasons for selecting TRANSYT-7F are: (1) its traffic model has recently been extended to overcome oversaturated traffic conditions; and (2) Genetic Algorithm has recently been added for optimization purposes which is an efficient tool for global optimization.

3 TRANSYT-7F Model

TRANSYT-7F is a deterministic, macroscopic simulation and optimization model. Accordingly, TRANSYT-7F model consists of a simulator and an optimizer.

3.1 TRANSYT-7F Simulator

The traffic model simulates traffic behavior in a roadway network which consists of junctions mostly controlled by traffic signals. This traffic simulator calculates the value of a 'performance index' (PI) for the network for a given fixed-time plan and an average value of flow on each link [7].

In TRANSYT-7F traffic simulator, the following basic assumptions are made [17]: (1) traffic rate of flow on each approach is constant; (2) the left/right turning percentages at each approach remain constant throughout the simulation period; (3) all major intersections in the system are controlled by signals or by a priority rule; and (4) all intersections in the system have a common cycle time or some multiple of a common cycle.

TRANSYT-7F uses the common modeling of traffic networks by graphs with nodes and links. In this system, each intersection is represented by a node and each one-way traffic movement between two nodes is represented by a link.

In TRANSYT-7F traffic flow model, the simulation is carried out by calculating the following three types of flow profiles which are IN profile, OUT profile and GO profile. "The IN profile is the pattern of traffic that would arrive at the stop line at the downstream end of the link with a condition of not impeding the traffic by the signals at that stop line. The OUT profile is the pattern of traffic that departs from the link. The GO profile is the pattern of the traffic that would leave the stop line if there is enough traffic to saturate the green." The downstream arrival flow on internal links for each time step, t, is calculated by the following recurrence equation [17]:

$$q^1_{t+\beta T} = F \cdot q_t \cdot p + (1-F) \cdot q^1_{t+\beta T-1} \quad (1)$$

$$F = \frac{1}{1+\alpha \cdot \beta \cdot T} \quad (2)$$

where: $q^1_{t+\beta T}$ – predicted downstream flow rate in time interval t+BT of the predicted platoon; q_t – flow rate of the initial platoon (OUT-profile) during step t; p – the proportion of the OUT flow entering this link; β – an empirical factor, generally 0.8; T – the cruise travel time on the link, in steps; F – a smoothing factor; α– an empirically derived constant, called the platoon dispersion factor; and T – the cruise travel time on the link from the upstream stop line to the downstream stop line.

TRANSYT-7F uses the Highway Capacity Manual 2000 delay model. The model predicts average "control" delay, which contains initial deceleration delay, queue move-up time, stopped delay, and final acceleration delay. See National Research Council [18] or Hale [7] for more detail on delay calculation.

3.2 TRANSYT-7F Optimizer

The optimizer adjusts the settings of signal timing plan and examines if the adjusted settings better the performance index using the traffic simulator. The process is repeated until an optimum timing plan is reached.

In TRANSYT-7F optimizer, an objective function, the performance index (PI), is maximized (or minimized). The user can select the objective function depending on the desired operational characteristics of the system under consideration. The standard TRANSYT-7F Disutility Index (DI) is one of the performance indices which is a linear combination of the "standard" delay and stops.

The maximization/minimization in TRANSYT-7F optimizer is based on genetic algorithm optimization technique. It is a theoretical improvement over the traditional hill-climb optimization technique that has been employed by TRANSYT-7F for many years. Genetic algorithm has the ability to avoid becoming trapped in a "local optimum" solution, and is mathematically best qualified to locate the "global optimum" solution. For more description of genetic algorithm optimizer, see Hale [7].

4 Data

4.1 Geometric Data

The study area is a part of Eljalaa Street consisting of five consecutive signalized intersections. A sketch of the street is presented in Figure 1. The spacing between intersections ranges between 276m to 506m. The name of intersections and geometric characteristics are summarized in Table 1. The Table presents the number of lanes in each approach before arriving and at each intersection. It is noted that the lanes before arriving intersections is less than at intersections because of either widening of intersections or using nearside lane for parking between intersections. Intersection 1 is T-intersection; thus the number of lanes in the north bound is not available. Although intersection 4 is cross intersection in reality, the east bound approach is not used because of maintenance at this approach. The work at the approach is not finished until now because of the siege of Gaza Strip started four years ago.

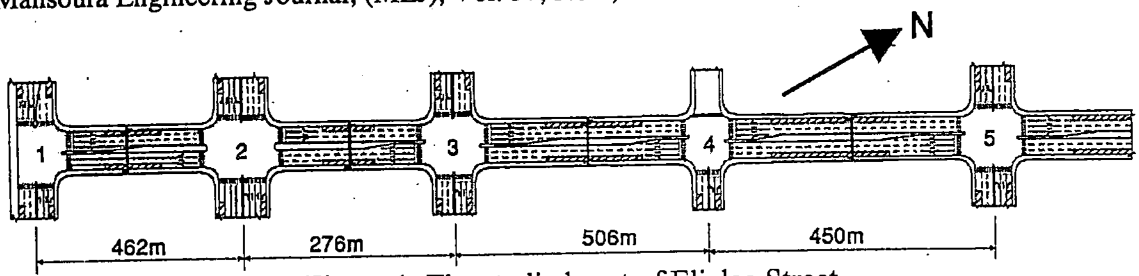


Figure 1. The studied part of Eljalaa Street

Table 1: Geometric characteristics of the studied five intersections

No.	Name	Eljalaa St. With...	before intersection For NB	SB	EB	WB	At intersection For NB	SB	EB	WB
1	El-Tiaran	Jamal Abdennaser	-	2	2	2	_	4	3	3
2	El-Saraya	Omar Elmokhtar	2	2	2	2	3	3	4	4
3	Dabeet	El-Wehda	2	2	2	2	4	4	3	3
4	El-Barbary	Tarek Bin Zeyad	2	2	-	1	4	4	_	2
5	El-Ghifary	El-Lababedi	2	2	2	2	4	4	3	3

NB: North bound; SB: South bound; EB: East Bound; WB: West Bound

4.2 Traffic Count

Manual traffic count was used in this work. Because of financial constraint and lack of human resources, the traffic count was conducted on Sunday 21/10/2007 in the evening peak period. The form of manual traffic count is shown in Figure 2. The general information required to fill in the form are intersection number, intersection name, name of counted approach, observer name, weather condition, date and sheet number. The traffic count was carried out every 15 minutes, which is usually used for traffic analysis and design. Thus, each traffic period requires one counting sheet; and the start and end of this period must be written in the general information at the top of the count form.

At each approach three movements are considered for traffic count. These are left-turn, through and right-turn movements. In each movement the traffic count is classified into 7 categories. The first category is Car/Van which is defined in this work as all vehicles that have two axles. Bus is all vehicles that have passenger capacity of about 50 persons. The third category is Truck which is all vehicles that have three or more axles. The forth is Bike and the fifth is Motorcycle. The sixth is Tractor. The last one is Cart which is the animal driven cart.

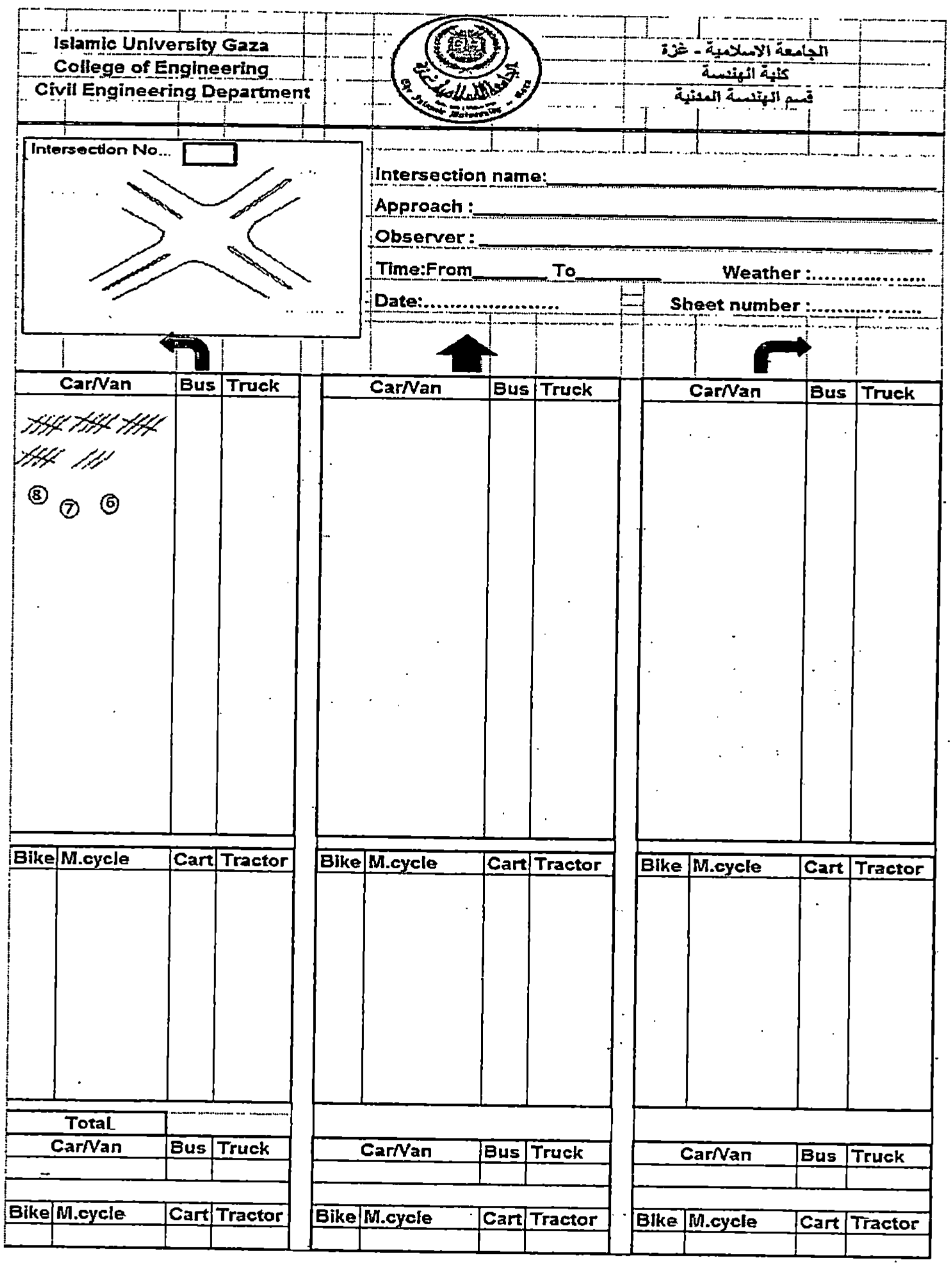
The traffic count was carried out with classification since the traffic composition has an effect on the capacity of traffic signal approaches. The effect of traffic composition on capacity is usually considered by the use of weighting factors, referred to as 'passenger car units', assigned to differing vehicle categories. Constant factors are used to convert all vehicle types into passenger car units (pcu) value. Values of pcu to be used for signal analysis and design are as shown in Table 2 ([19], [20]).

Table 2: pcu for for different types of vehicles

Vehicle type	pcu value
Car/Van	1.0
Bus	2.0
Truck	2.3
Bike	0.2
Motor cycles	0.4
Tractor	1.5
Cart	3

When each vehicle enters the intersection, a slash mark is written until reaching 4 vehicles. Then, when the fifth vehicle enters the intersection, a slash is written across the four slashes. This is for making the calculation of total volume easier. At heavy intersections using slash marks might be difficult to follow up. Therefore, one may use numbers for each group of vehicles as indicated in Figure 2.

The peak hour was between 11:45-12:45 and the peak 15-minutes period was between 12:30-12:45. This period will be considered for analysis and signal coordination based on TRANSYT-7F in the next section. The traffic volume for left-turn, through, and right-turn movements at each intersection in this 15-minutes period are presented in Table 3.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كلية الهندسة
قسم الهندسة المدنية
Intersection No...
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Sheet number :..................

Car/Van	Bus	Truck	Car/Van	Bus	Truck	Car/Van	Bus	Truck
⑧ ⑦ ⑥								

Bike	M.cycle	Cart	Tractor	Bike	M.cycle	Cart	Tractor	Bike	M.cycle	Cart	Tractor

Total

Car/Van	Bus	Truck	Car/Van	Bus	Truck	Car/Van	Bus	Truck

Bike	M.cycle	Cart	Tractor	Bike	M.cycle	Cart	Tractor	Bike	M.cycle	Cart	Tractor

Figure 2. Form of manual traffic count

4.3 Current Signal Timing Plan

The existing signal timing at the considered intersections are presented in Table 4. The lengths of the cycle time for the intersections shown in the table are not equal which reveal that Eljalaa arterial is not coordinated. The values of offsets for all intersections are zeros, which is another evidence of not using the signal coordination. The phase number, description and its value of green time are shown in the Table. The abbreviations RS+LS+TE in the phase description column mean that phase 1 at intersection 1 consists of right turn movement in the south approach (RS); left turn movement in the south approach (LS); and through movement in the south approach (LS).

Table 3: Traffic volume in the peak 15-minutes (pcu/hr) in the peak hour for each traffic movement at each intersection

Intersection Number	Traffic Volume in the peak 15-minutes (pcu)											
	North Bound			South Bound			East Bound			West Bound		
	L	T	R	L	T	R	L	T	R	L	T	R
1	-	-	-	150	-	105	109	149	-	-	121	106
2	38	122	55	51	152	43	77	120	33	68	92	34
3	36	134	63	72	162	40	28	59	38	40	111	97
4	-	256	10	14	257	-	-	-	-	66	-	10
5	51	209	10	10	221	32	37	10	43	10	14	12

L: Left-turn Movement; T: Through Movement; R: Right-turn Movement

Table 4: Existing signal timing plan for the considered intersections

Intersection Number	Cycle time (sec)	Offset (sec)	Phase no.	Phase Description	Green time (sec)
			1	RS+LS+TE	40
1	95	0	2	LE	25
			3	TW+RW	30
			1	LN+TN+RN	25
2	110	0	2	LS+TS+RS	30
			3	LE+TE+RE	25
			4	LW+TW+RW	30
			1	LN+LS	20
3	95	0	2	TN+RN+TS+RS	30
			3	LE+TE+RE	20
			4	LW+TW+RW	25
			1	TN+RN	35
4	95	0	2	TS+LS	35
			3	LW+RW	25
			1	LN+LS	20
5	95	0	2	TN+RN+TS+RS	30
			3	LE+TE+RE	20
			4	LW+TW+RW	25

L: Left-turn Movement; T: Through Movement; R: Right-turn Movement; N: North Bound, S: South Bound, E: East Bound, W: West Bound.

5 Signal Analysis and Coordination

5.1 Signal Analysis

To analyze the traffic performance of existing uncoordinated situation of Eljalaa arterial, geometric and traffic data are input to TRANSYT-7F software. TRANSYT-7F predicts different performance measures for evaluation such as Total Travel Time, Level of Service, Average Delay, Stops Percentage, Fuel Consumption, and Performance Index. The Performance Index measures the overall cost of traffic congestion and is usually a combination of the total delay and the number of stops made by vehicles.

Table 5: Performance of existing uncoordinated situation of Eljalaa Arterial

Performance Measures	Units	Total
Total Travel Time	veh-hr	86
Average Delay	sec/veh	57.8
Total Stops:	%	113
Fuel Consumption	Liter	467
The Disutility Index	DI	384

Table 5 presents the results of analysis for the whole system of existing uncoordinated traffic situation in terms of the different performance measures obtained by TRANSYT-7F. The results show high amount of performance measures experienced during the peak period by most of the travelers. The results indicate that Eljalaa route is highly congested. Delay obtained 57.8 sec/veh with reference to TRB [18] dictates level of service (LOS) E. Also travel time had a value of 86 veh-hr.

5.2 Signal Coordination

In order to reduce the traffic congestion, the existing timing plan has to be redesigned such that the signals along Eljalaa arterial are coordinated. This can be achieved using TRANSYT-7F by optimizing common cycle time, green splits and offsets based on Genetic Algorithm available in the software. The values of Genetic Algorithm parameters used in the optimization are 30% for crossover probability; 1% for mutation probability; 0.01% for convergence threshold; 100 for maximum number of generations; and 50 for population size.

The results of optimum values of signal timing parameters are presented in Table 6. The common cycle time is 80 seconds, which is less than any cycle length for all intersections in the uncoordinated existing plan. This means that the existing timing plan is not proper calculated. The offsets for intersections 1, 2, 3, 4 and 5 are 0, 10, 25, 23, and 35 seconds respectively indicating of signal coordination.

The performance results for the whole coordinated arterial are presented in Table 7. The results show reduction in the amount of travel time, delay, stops, fuel consumption and disutility index. The benefits of coordination are clearly visible. For the whole system, the Total Travel Time comes down to 59 veh-hr, from 86 veh-hr, an improvement of about 31.4%. The results show that the average delay faced by the vehicles has dropped from 57.8 sec/veh to 30.9 sec/veh during the peak hour indicating improvement of 46.5%. The LOS has been changed to a better value of D. The Total Stops, Fuel Consumption and Performance Index have been decreased to significant values.

Table 6: Design of signal timing plan for the considered intersections

Intersection Number	Cycle time (sec)	Offset (sec)	Phase no.	Green time (sec)
1	80	0	1	22
			2	31
			3	27
2	80	10	1	21
			2	24
			3	19
			4	16
3	80	25	1	11
			2	30
			3	16
			4	23
4	80	23	1	23
			2	26
			3	31
5	80	35	1	9
			2	49
			3	13
			4	9

The comparison based on Total Travel Time, Level of Service, Average Delay, Stops percentage, Fuel Consumption, and Performance Index for whole segment of arterial during peak hour at all approaches is shown in Figure 3. The impact of the coordination system is obvious from the fact that there is a significant reduction in the value of all performance parameters.

Table 7: Performance of signal coordination of Eljalaa Arterial

Performance Measures	Units	Total	% of decrease
Total Travel Time	veh-hr	59	31.4
Average Delay	sec/veh	30.9	46.5
Total Stops	%	87	23.0
Fuel Consumption	Liter	365	21.8
Performance Index	DI	258.4	32.7

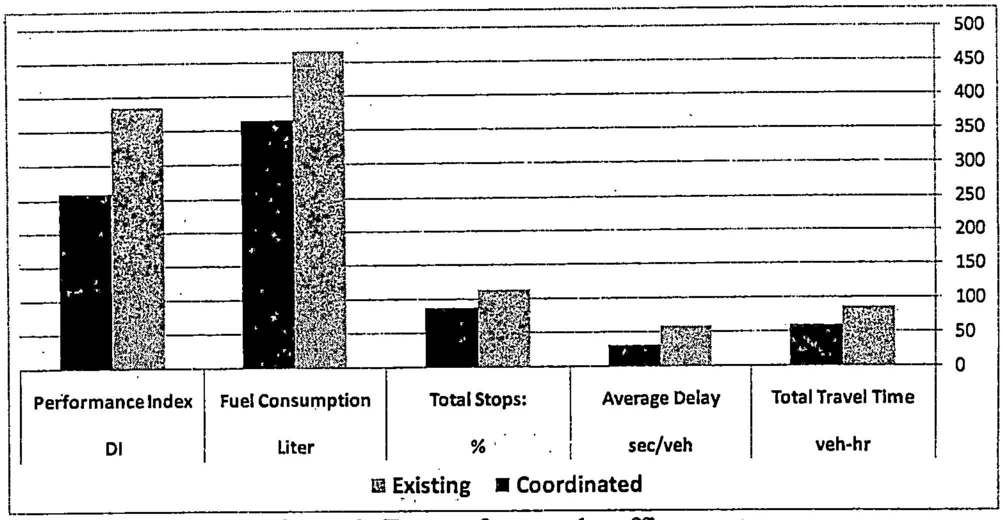

Figure 3. Form of manual traffic count

6 Conclusion

Travellers along Eljalaa arterial, located in Gaza city, suffer from traffic congestion which is a result of non efficient traffic signal control. The signals at the arterial are not coordinated; each intersection at the arterial is treated as an isolated one. Another reason for traffic congestion is that the timing setting is normally developed without proper calculations; but, it is usually assigned based on experience. This study intends to evaluate the existing uncoordinated timing plan for the arterial, and then redesign a new timing plan ensuring signal coordination using TRANSYT-7F.

Geometric data was collected which includes speed, medium width and number of lanes of each approach at each intersection. For each lane, information about length and width in addition to the lane use by movement were also obtained. Classified manual traffic count was carried out on Sunday 21/10/2007 in the evening peak period. The peak hour was between 11:45-12:45 and the peak 15-minutes period was between 12:30-12:45. The volume in this peak 15-minutes period was used for analysis and signal coordination.

The results of analysis of the existing uncoordinated arterial show a bad level of service (E) for the whole system. This indicates that Eljalaa arterial is highly congested. When timing plan is optimized and the signals are coordinated, a major improvement in the traffic performance is obtained. The performance index (disutility index) which incorporates Total Travel Time, Average Delay, Total Stops and Fuel Consumption has been significantly reduced by 32.7%. The level of service has been changed from E to D.

Several recommendations have emerged from this research. First, different traffic volumes require different signal timing plans. Therefore the same work should be carried out for different periods of time of day. Second, other arterials are recommended to be coordinated in the same way. Third, when the economical situation is better, it is recommended to install sensors at intersections and to use actuated traffic responsive control.

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