REFERENCES

1. L.H. Adams. Executive Summary System Support Alternatives Integrated Motorist Information System National Test Center. Traffic and Safety Division, New York State Department of Transportation, Albany, 1982.
2. Performance of Commercial Activities. Supplement Circular No. A-76. Office of Management and Budget, Executive Office of the President, Washington, D.C., Jan. 1984.

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Platoon Dispersion over Long Road Links

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ABSTRACT

The dispersion of platoons of vehicles as they travel between signalized intersections reduces the potential benefits from coordinating traffic signal timings. The effects of dispersion place a limit on the distance between intersections over which it is beneficial to provide coordination. During a feasibility study for a traffic control system, platoons were observed to remain together for distances up to 2000 m on high-standard arterial roads. Platoon shapes were measured and the results were compared with predictions of the TRANSYT signal timing program by using various values for the TRANSYT platoon dispersion factor. Despite the unusually long distances involved, the most suitable dispersion factor values fell in the same range as those normally used for networks of more typical dimensions. Optimized timings were not found to be unduly sensitive to the dispersion factor used. Requirements to minimize delay throughout the network, and not just on an individual link, act as a constraint on the sensitivity of TRANSYT timings to platoon dispersion rates. On the basis of the observation of platoons on high-standard arterial roads, it was conservatively estimated that coordinated signals could reduce delay by 10 percent, where distances between signals ranged between 1000 and 1500 m.

The dispersion of groups of vehicles as they travel away from a signalized intersection is a familiar characteristic of traffic, created by the differences in speed of travel of the individual vehicles. Models of signalized road networks, including those used within programs to calculate coordinated signal timings, need to account for this phenomenon to provide an accurate representation of vehicle behavior.

The benefits of coordinating neighboring traffic signals are derived through careful timing of the green signals to coincide with the arrival of platoons of traffic from upstream intersections. The longer the distance between intersections, the more dispersed the platoons become and the smaller are the potential benefits from coordination.

Platoon dispersion frequently imposes an upper limit on the distance between intersections over which it is beneficial to provide signal coordination capabilities. This limit is typically between 500 to 1000 m for most road networks. Described in this paper are measurements of the rate of platoon dispersion in a network of arterial roadways of high standard. Through these descriptions, the potential for worthwhile benefits as a result of coordination over distances of 1500 m is demonstrated.

CONTEXT OF STUDY

In many feasibility studies for coordinated signal systems, it is adequate to simply observe, but not directly measure, platoons as they reach the next downstream intersection and base estimates of benefits on results obtained from other cities with similar characteristics. Relevant characteristics include city size, type of network (grid, arterial, or both), sophistication of existing signal equipment (coordinated or not) and average distance between signals.

However, in a feasibility study conducted in the city of Kuwait, the distance between signals was sufficiently long in parts of the roadway network for special studies of platoon dispersion to be undertaken so that the benefits of signal coordination could be estimated. These studies included analysis of platoon dispersion factors to be used in a coordinated signal timing program for this network and an evaluation of the sensitivity of the optimized timings to the value of factor used. This paper contains descriptions of these studies and presents the conclusions reached.

The work was divided into four phases, as follows:

1. Platoon dispersion surveys,
2. Dispersion analysis,
3. Sensitivity of coordinated timings to rate of dispersion, and
4. Estimate of benefits through coordination of signals over long links.

Each phase of the work is described. First, however, it is necessary to briefly describe those characteristics of the Kuwait road system that gave rise to these efforts.

ROAD NETWORK CHARACTERISTICS

Kuwait is the principal city of the country of the same name, situated on the northwest shores of the Arabian Gulf. The country, with a 1980 population of 1.367 million, enjoys a high standard of living as a result of substantial oil reserves. The existing system of roads is the result of many years of careful planning and subsequent execution of these plans. The road system in the urban area of the city is shown in Figure 1.

Within the First Ring Road lies the oldest part of the city, known as Kuwait Town. The central business district (CBD) is contained in this area, and it encompasses large centers of employment, retail activity, and government complexes.

Outside of the First Ring Road, the roads that provide access through the urban area form a network of well-defined radial routes and ring roads. Each of these facilities has been designed and constructed to a high standard. Distances between major intersections along the arterial and ring roads are typically in the range of 1 to 2 km. The radial and ring roads are divided roadways with generally three lanes of travel in each direction. Until recently, all intersections were at grade, in the form of roundabouts, or conventional signal-controlled intersections. Some intersections have now been converted to grade separated, with signalized ramp terminals forming diamond interchanges.

Of equal importance to the high standards of design of the radial and ring roads is the fact that access to the adjacent residential districts is only possible by turning right off the main road at a point midway between intersections (driving is on the right-hand side of the road). Access from the districts is achieved by turning right on the radial or ring roads at a stop sign. This limited access to and from neighboring residential areas gives rise to a comparatively low level of skin friction effects for an urban area, which allows traffic to flow smoothly and rapidly between major intersections.

Other factors also contribute to the smoothness of flow between intersections. First, outside the industrial area to the west of the city, the vehicle mix is dominated by modern passenger cars with comparatively few heavy trucks. Second, the number of public transport vehicles is not large (although it is increasing) and bus lay-bys are provided at all bus stops to minimize the disruption to near-side lane traffic. Pedestrian activity is limited, with

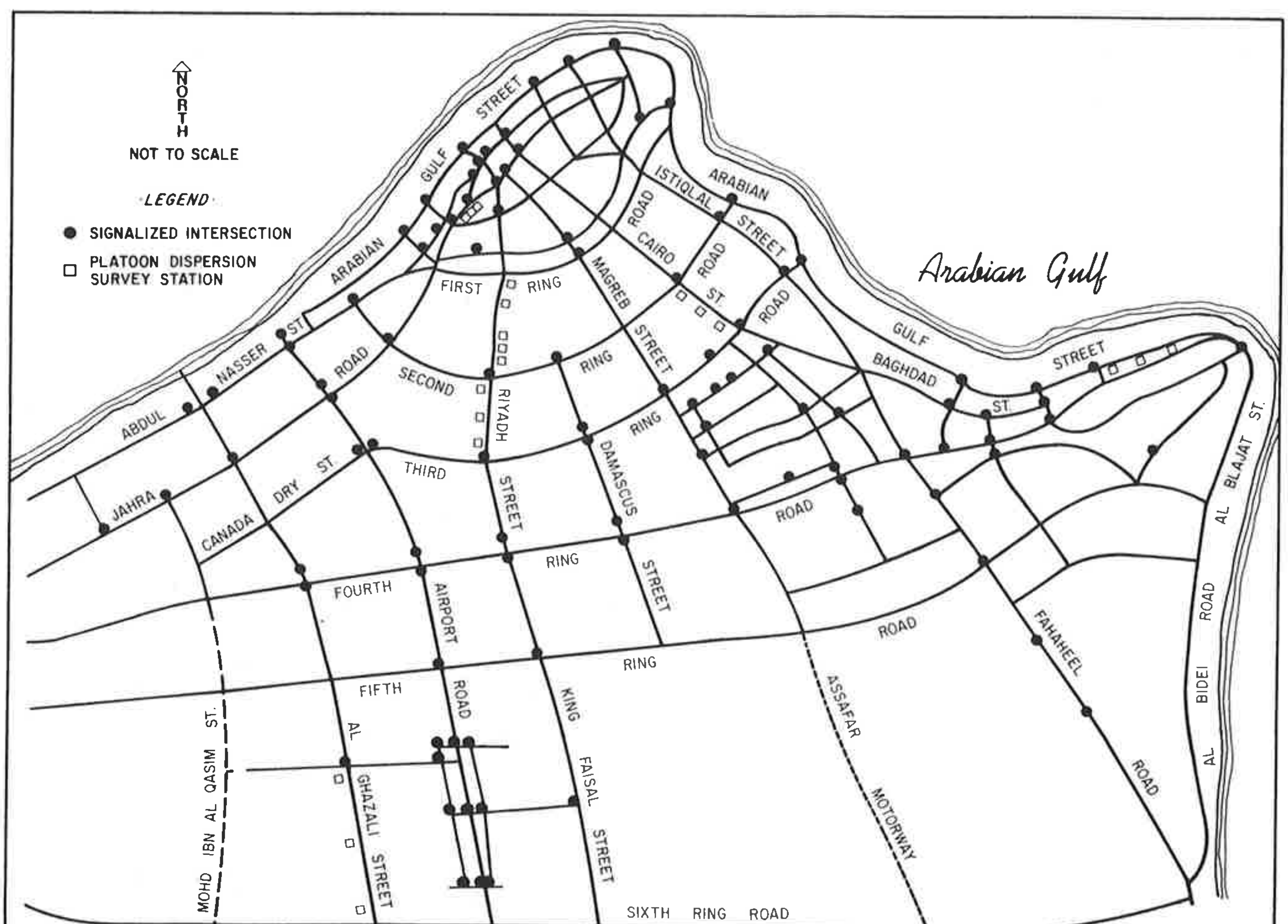

FIGURE 1 The roadway network in Kuwait.

overhead pedestrian bridges being available at numerous locations. Curb parking is not permitted.

In summary, the intersections of radial and ring roads are separated by divided roadways of high standard, along which traffic is able to travel smoothly and rapidly. Although distances between intersections are greater than normally associated with coordination, the special characteristics described previously encouraged efforts to estimate the likely benefits from coordinated signals on the radial and ring roads. As a first step, a survey was conducted to measure the rate at which platoons of vehicles disperse on the Kuwait road network.

PLATOON DISPERSION SURVEY

The purpose of the survey and subsequent analysis was to measure the extent to which traffic remains within a platoon over long distances and to derive an equation that incorporates Kuwait driver characteristics to predict platoon dispersion for use in signal timing plan calculations.

The surveys were conducted along a number of arterial roads and on Fahd Al-Salem Street in Kuwait Town. Six staff members were paired up into counting teams A, B, and C. A seventh staff member operated on his own, monitoring the green signal that released the platoon of traffic to be measured. A schematic diagram that illustrates the typical disposition of field staff is shown in Figure 2. Team A was positioned close to the exit of the signalized intersection, generally just after the right-turn loop entered the main road. Teams B and C were located downstream of A at varying distances from A up to 2.2 km.

Each team and the signal observer were equipped with a synchronized clock. At a preset time, each team commenced its duties. One member of each team counted traffic for periods of 5 sec. To assist him, he was provided with his own clock, which emitted a sharp tone every 5 sec. On hearing the tone, he was to call out the count from the last 5-sec period and this was then recorded by the second team member. Each survey was conducted for 30 min. Average journey times were also measured between the positions of teams A, B, and C by the moving observer method.

Survey locations were chosen to permit analysis over as wide a range of distances as possible. To ease subsequent analysis, preference was given to locations with the following features, although these were by no means present in all cases (a) left turns not permitted from the cross street at the upstream intersection, (b) low volumes of traffic entering or leaving the main road between survey stations, and (c) signal controller at the upstream intersection operating in fixed-time mode.

It should be emphasized that the first two criteria were adopted to isolate, to the maximum extent possible, the platoon dispersion phenomenon to be measured. It was, of course, recognized that turning movements at both the upstream intersection and along the road itself have an important bearing on the subject of coordination and benefits that may be derived.

The locations used in the platoon dispersion survey are listed in Table 1. The surveys conducted on Fahd Al-Salem Street were included to permit the platoon dispersion rates on the arterial roads of Kuwait to be compared with those in Kuwait Town.

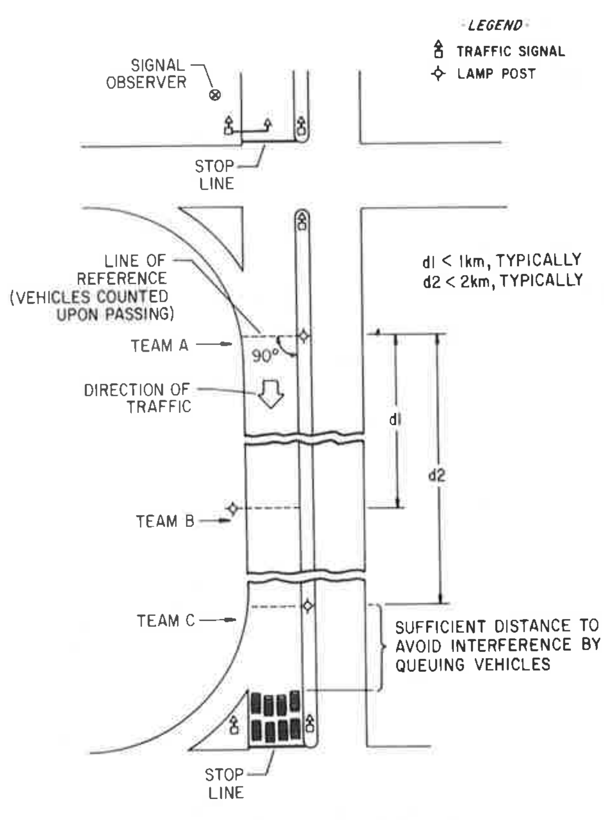

FIGURE 2 Position of observers for platoon dispersion survey.

PLATOON DISPERSION ANALYSIS

One of the most widely used models of platoon dispersion is contained within the TRANSYT signal timing program developed by the Transport and Road Research Laboratory (TRRL) in England (1). This model predicts the number of arrivals in an interval of time at a point downstream of a signalized intersection by use of the following equation:

$$Q'_{i+t} = [Q_i \times F + Q'_{i+t-1} \times (1 - F)] \quad (1)$$

where

- Q'_{i+t} = number of arrivals in interval i + t at a point downstream of a signalized intersection,
- Q_i = number of departures in interval i from the signalized intersection,
- F = function of journey time between the intersection and the downstream point, and
- t = 0.8 x the average journey time, expressed in intervals of time.

The smoothing factor F is expressed as

$$F = 1/[1 + (K \times t)/100] \quad (2)$$

where K is a constant.

The value recommended for K in the TRANSYT documentation for the original program and in versions through, to, and including TRANSYT 7 is 50 (1-3). This value has since been revised by TRRL to 35 (4). In Release 3 of TRANSYT 7F, issued by FHWA, 35 is the default value and a value in the range from 25 to 50 is suggested depending on roadway characteristics (5).

Analysis of observations was conducted in such a way as to be compatible with the structure of the TRANSYT dispersion formula. This was conducted to permit a comparison to be made of the predictions of the TRANSYT model and observed conditions on the arterial roads in Kuwait. The principal steps in the analysis may be summarized as follows:

TABLE 1 Location of Platoon Dispersion Surveys

Station No.	Location (team A)	Features: Left Turns	Features: Signal Control	Location (teams B and C): Station No.	Distance D1 (m)	Station No.	Distance D2 (m)
1	Riyadh Street south of Second Ring Road	Banned[a]	Fixed	2	430	3	953
2	Cairo Street south of Second Ring Road	Allowed	Police	5	600	6	931
7	Riyadh Street north of Second Ring Road	Banned[a]	Fixed	9	551	11	1343
7	Riyadh Street north of Second Ring Road	Banned[a]	Fixed	8	168	10	953
12	Fahd Al-Salem Street east of Hilali Street	Allowed	Fixed	13	130	14	260
12	Fahd Al-Salem Street east of Hilali Street	Allowed	Police	13	130	14	260
15	Ghazali Street south of Jordan Street	Allowed	Fixed	16	1100	17	2200
18	Arabian Gulf Street westbound between Qatar and Salem Al-Mobarak	Allowed	V/A	19	1000	20	2000

Note: V/A = vehicle-actuated.
Source: Wilbur Smith and Associates, Columbia, S.C.
[a]Left turns were banned at these survey locations, but illegal left turners were observed and counted by survey team A.

1. Calculate the average observed platoon shape at each survey station (i.e., calculate the number of vehicles that passes a station in each 5-sec interval) in the average signal cycle and plot the resulting platoon.
2. By using Equations 1 and 2, calculate predicted flows in each time interval that pass the downstream survey stations, where Teams B and C are located, from the average platoon observed by Team A by using various values of platoon dispersion factor K.
3. Compare the predicted platoons with the platoons observed by Teams B and C.

Sample Analysis of Observed Platoons on Riyadh Street

The number of vehicles that passes a station in each time interval within the signal cycle was averaged over the 30-min period of the survey. With cycle times of 2.5 to 3 min being used, the average platoon shape at a station was therefore derived over approximately 10 signal cycles. The average platoons observed at Stations 1, 2, and 3 on Riyadh Street south of the Second Ring Road (southbound) are shown in Figure 3.

Predicted platoon shapes at the downstream survey stations, B and C, were calculated by using the TRANSYT formula for a number of alternative values of K. The values of K investigated were 50, 40, 35, 30, and 20. For each alternative predicted platoon, a measure of the prediction's degree of similarity with the observed platoon was calculated. This measure was expressed as the sum of the squares of the differences between observed and predicted flows in each increment of time.

The dispersion factor for which the prediction measure was a minimum was taken as the most suitable value. Let this value of K be called K_{min}. Two predicted platoons were then plotted with the observed platoon at the downstream team locations (B and C). These platoons were predicted with K equal to 50 (the original standard TRANSYT value) and K equal to K_{min}. Predicted platoons are shown in Figure 4 for southbound traffic on Riyadh Street.

It can be seen that the value of K = 50 predicts a slightly greater degree of platoon dispersion than was observed during the survey on Riyadh Street. A smaller value of K in the TRANSYT formula, in this case 30, leads to a predicted platoon in closer agreement with the observations made.

The shape of the average platoon as it leaves a signalized intersection is an essential input to the TRANSYT platoon dispersion formula. To derive a meaningful average platoon from the observed data, the analysis described earlier was restricted to those survey sites for which the upstream intersection controller was operating in a fixed-time mode. The value of the constant K_{min} found for each survey station is shown in Table 2. Also shown are the measured travel times to each station and the average speeds between survey stations.

Prediction of Platoon Dispersion on Roads in Kuwait

Observations made in this survey indicate that the form of equation in the TRANSYT program for modeling platoon dispersion is suitable for predicting dispersion along arterial roads in Kuwait. Different values of K in the TRANSYT formula yielded predicted platoon patterns that were basically similar to each other. The small differences that were obtained were those to be expected from examination of the TRANSYT equation. A smaller value of K results in a larger factor F and, hence, a prediction of greater platoon cohesion (or less dispersion) than larger values of K.

A value for K of 50 was found to be the most suitable for predicting platoon dispersion on the arterial Gazhali Street and on Fahd Al-Salem in the CBD. It is thought that the the free flowing conditions on Gazhali Street, which are normally conducive to a high degree of platoon cohesion, may have been offset by the extremely high speeds, averaging 90 km/hr. On Riyadh Street, platoons were found to retain their formations to a slightly greater extent and a K value between 30 and 40 was found to be more appropriate. Despite the very wide range of distances surveyed (168 to 2200 m), these values of K are in line with the values commonly used in many urban road networks with distances between intersections in the more common range of 100 to 500 m.

The TRANSYT program permits the rate of platoon dispersion to be specified on an individual road link basis, if necessary, by the optional input of the desired K value. In the absence of this item of data for a link, the program uses a default value of K = 35. The sensitivity of the optimized timings to the value used for K was examined in subsequent analysis.

SENSITIVITY OF TIMING PLANS TO RATE OF PLATOON DISPERSION

The platoon dispersion survey indicated that the rate of dispersion was not constant. On some roads the rate was observed to be equivalent to the TRANSYT dispersion factor K of 50. On other roads, however, platoons were observed to retain their formations to a slightly greater extent, which corresponds to a K value of 30 or 40.

These findings raised the question of the sensitivity of TRANSYT signal timings to the value of the dispersion factor specified in the program data for

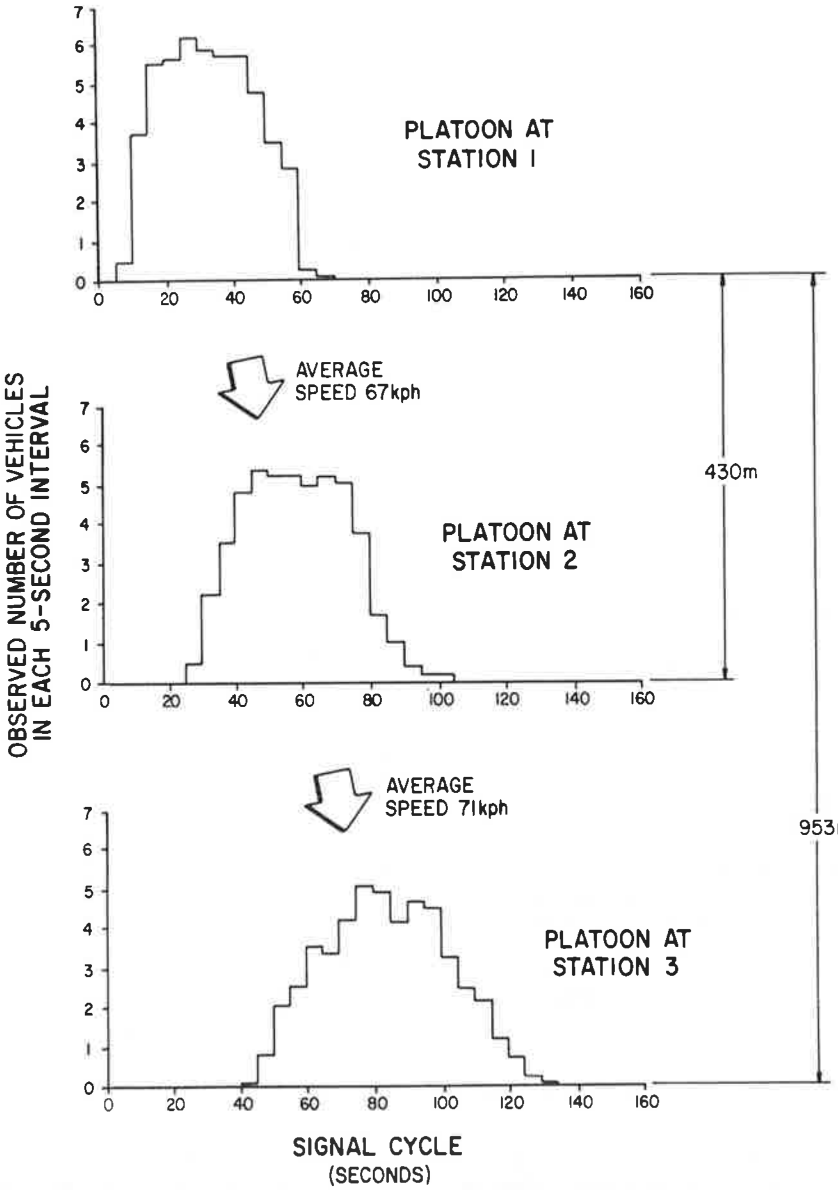

FIGURE 3 Observed platoon dispersion southbound on Riyadh Street between Second and Third Ring Roads.

each link. To examine this sensitivity, data were prepared for a small network, and a total of 18 TRANSYT runs was performed. The network, shown in Figure 5, involved five intersections that correspond to those on Riyadh Street at Second, Third, and Fourth Ring Roads and Damascus Street at Second and Third Ring Roads. The distance between intersections in this network ranged from 1050 to 1450 m.

Description of Analysis

Optimized fixed-time plans were calculated for two sets of traffic flows, which correspond to conditions between 7:00 and 8:00 a.m. and between 5:00 and 6:00 p.m. For simplicity, the following description of nine program runs refers only to the a.m. flows. However, a corresponding set of nine runs for the p.m. conditions was also performed.

An optimized plan was first calculated by assuming that the rate of dispersion along links corresponded to a dispersion factor K of 50. Let the optimum performance index (total delay in vehicle hours per hour plus weighted number of vehicle stops) that results from this plan be denoted by I_{t50}. The weighting factor for stops was given the moderate value of 10 in all runs. A second optimized plan was then calculated by assuming a dispersion factor of 40 and a performance index of I_{t40} was obtained. A final optimized plan for K = 30 was then produced and I_{t30} was calculated. Table 3 shows symbols for the optimized performance indices I_{t30}, I_{t40}, and I_{t50} being positioned as the diagonal elements of a 3 x 3 matrix of performance indices.

A series of six nonoptimizing TRANSYT runs was then performed in which the program merely simulated the effect in terms of delay and number of stops, which would result from a specified set of signal timings. In the first such run, signal timings were fixed at the optimized values found earlier with K = 50, but the link data were such that the simulation model would disperse platoons at a rate equivalent to K = 40. Let the performance index calculated in this run be denoted by $I_{t50/40}$. This symbol is

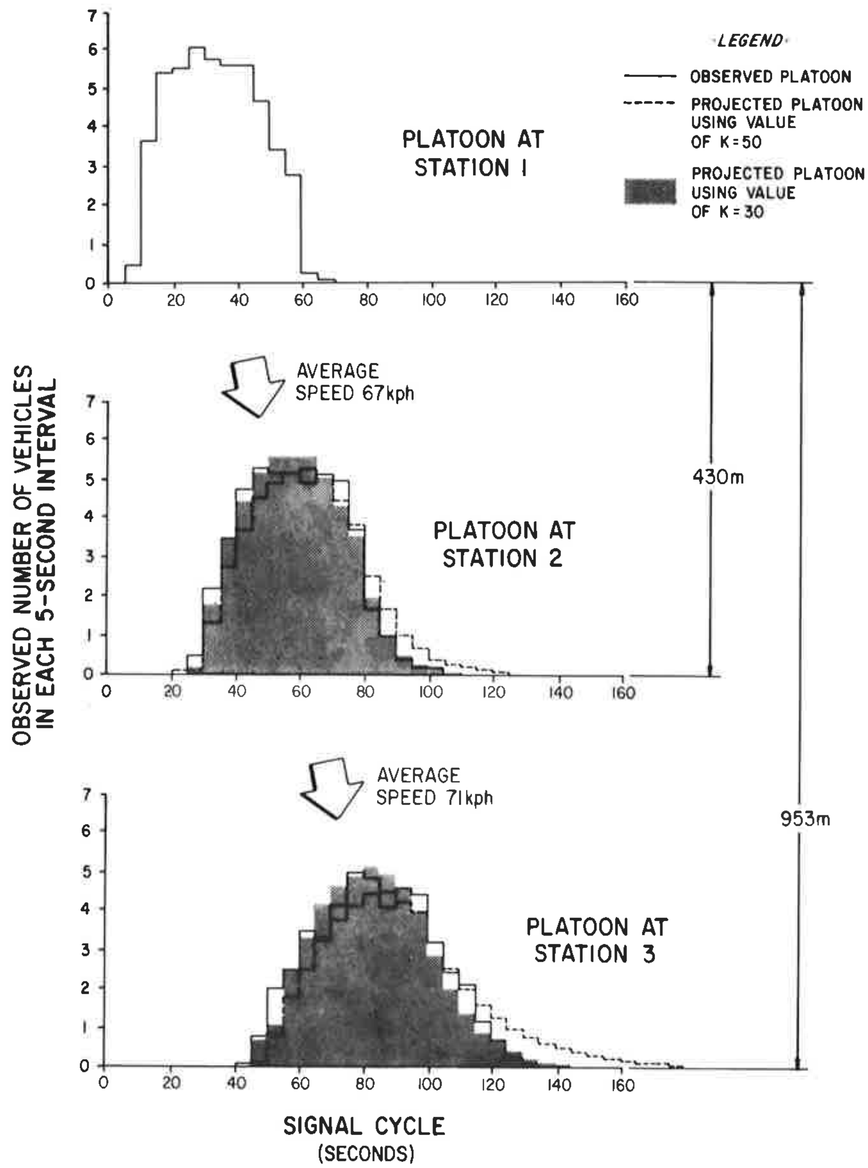

FIGURE 4 Predicted platoon dispersion southbound on Riyadh Street between Second and Third Ring Roads.

TABLE 2 Values of K_{min} Found for Some Arterial Roads in Kuwait

Distance from Location of Team A (m)	Survey Station No. (B or C)	Values of K_{min}	Journey Time (sec)	Average Speed (km/hr)
168	8	35	10.2	59.0
430	2	30	23.0	67.3
551	9	35	30.8	64.4
953	10	30	51.7	66.4
953	3	30	48.2	71.1
1100	16	50	47.5	83.4
1343	11	40	71.5	67.6
2200	17	50	87.8	90.2

shown as the middle element of the top row of the matrix of indices in Table 3. A comparison of the two indices $I_{t50/40}$ and I_{t40} indicates the extra delay and stops that would result from implementing a plan calculated with K = 50 if, in fact, platoons disperse at a slower rate equivalent to K = 40. The extra performance index above the optimum is given in this case by

$$\text{Extra performance index as a percentage of optimum} = 100 \times (I_{t50/40} - I_{t40} \quad (3)$$

Five further nonoptimizing runs of TRANSYT were performed to calculate $I_{t50/30}$, $I_{t40/50}$, $I_{t40/30}$, $I_{t30/50}$, and $I_{t30/40}$. These symbols are also shown in Table 3.

The numerical values obtained for all nine performance indices calculated during the a.m. peak flow runs are shown in Table 4, and the percentage increases in performance index that would result from each possible combination of fixed-time plan and simulation model assumptions on platoon dispersion rates are given in Table 5. Results for runs with the p.m. flow conditions are given in Tables 6 and 7. Layout of these results in a 3 x 3 matrix follows the format described previously for Table 3.

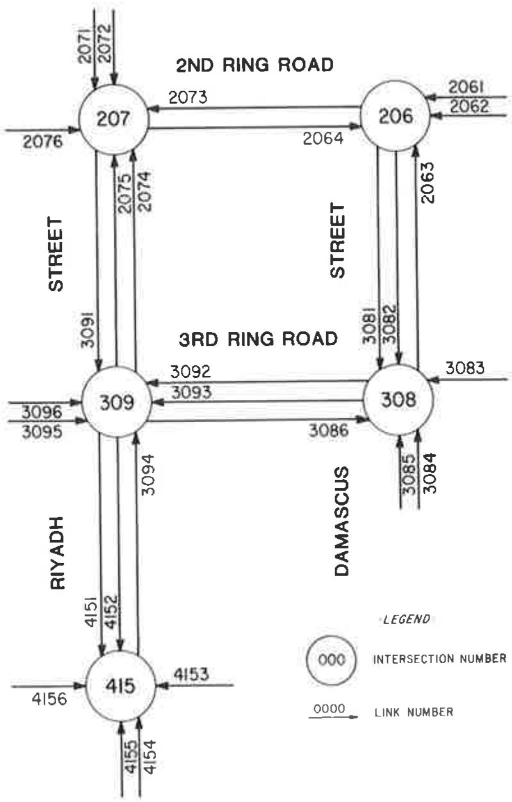

FIGURE 5 Five-intersection network of arterial and ring roads in Kuwait.

TABLE 3 Format for Presentation of Performance Index Values

Signal Timing Plan	Performance Index I by K Value		
	50	40	30
K = 50	I_{t50}	$I_{t50/40}$	$I_{t50/30}$
K = 40	$I_{t40/50}$	I_{t40}	$I_{t40/30}$
K = 30	$I_{t30/50}$	$I_{t30/40}$	I_{t30}

TABLE 4 Sensitivity of TRANSYT Plans to Dispersion Factor K—a.m. Flow Condition Results

Signal Timing Plan	Performance Index I by K Value		
	50	40	30
K = 50	372.58	369.12	366.47
K = 40	372.98	369.03	365.69
K = 30	378.39	372.32	365.38

TABLE 5 Sensitivity of TRANSYT Plans to Dispersion Factor K—a.m. Flow Condition Percentage Increase in Performance Index Above Optimum Value

Signal Timing Plan	Percent Increase in I by K Value		
	50	40	30
K = 50	–	0.02	0.30
K = 40	0.11	–	0.08
K = 30	1.56	0.89	–

TABLE 6 Sensitivity of TRANSYT Plans to Dispersion Factor K—p.m. Flow Condition Results

Signal Timing Plan	Performance Index I by K Value		
	50	40	30
K = 50	285.32	282.50	280.00
K = 40	286.61	282.38	280.42
K = 30	285.61	282.46	279.38

TABLE 7 Sensitivity of TRANSYT Plans to Dispersion Factor K—P.M. Flow Condition Percentage Increase in Performance Index Above Optimum Value

Signal Timing Plan	50	40	30
K = 50	–	0.04	0.22
K = 40	0.45	–	0.37
K = 30	0.10	0.03	–

Results of Sensitivity Analysis

The results indicate that the TRANSYT optimized plans are not particularly sensitive to the value used for the platoon dispersion factor K, in the 30 to 50 range. In only one of the cases examined would an incorrect assumption concerning platoon dispersion rates lead to additional delay and stops in excess of 1 percent of the optimum value.

This is not to say, of course, that different dispersion rates in this range do not produce noticeably different patterns of arrival at downstream stop lines. For example, the results indicate that for a given set of timings, the delay and stops may be up to 3.6 percent greater if dispersion is at the rate equivalent to K = 50 compared with the slower rate of 30 (see indices $I_{t30/50}$ and I_{t30} for a.m. flow conditions). However, these differences in arrival patterns gave rise to optimized plans whose timings differed from each other by only a very small amount. One of the reasons for this may be that although the timing optimization program may find benefits in increasing the percentage of green time for a link whose arriving platoon is more dispersed, there may be liabilities to other links at the same intersection when their green time is correspondingly decreased.

In effect, the requirement to minimize delay throughout the whole network, and not merely on an individual link, acts as a constraint on the potential sensitivity of TRANSYT plans to platoon dispersion rates. The result obtained suggest that for a wide variety of network configurations and characteristics, the use of the default platoon dispersion factor of 35 is quite adequate. The optimized timings found by TRANSYT appear to be sufficiently insensitive to the precise value of this factor that most users can expect satisfactory results by utilizing the program's default value.

COORDINATION BENEFITS ON ARTERIAL AND RING ROADS

To provide support for a judgment on likely benefits from the coordination of traffic signals on the long arterial and ring roads in Kuwait, a number of TRANSYT computer runs were performed to calculate delays on road links, first assuming that the signals at both ends of the link were coordinated and second, that they were not. Road lengths, traffic flows, signal phasing, saturation flows, and cycle times typical of Kuwait were utilized in preparing the data for these runs.

The rate of platoon dispersion assumed in these computer runs equaled the fastest rate observed during the platoon dispersion survey--the rate corresponding to a K value of 50. The fastest observed rate was used to provide a conservative estimate of the benefits as a result of coordination.

It should be noted that estimated benefits were based on a comparison of coordinated control with uncoordinated operation on the same cycle time. They therefore did not fully reflect the advantages of a modern traffic control system that permits timing plans with optimum cycle lengths to be implemented as traffic conditions change through the day--a facility not available with most existing fixed-time controllers in Kuwait.

Five-Intersection Arterial Network

The five-intersection network referred to earlier was included in a variety of performed runs. For this network, two optimized plans were calculated to cater to traffic conditions between 7:00 and 8:00 a.m. and between 5:00 and 6:00 p.m. Cycles of 150 and 120 sec were used for the morning and evening plans, respectively. The delays at traffic signals with these plans are given in Table 8 and are compared with the delay calculated if the signals were uncoordinated.

Links that feed intersections from outside the network are not able to derive any benefits from coordination. Considering only the internal links, therefore, the reduction in delay with coordination amounts to 18.4 and 19.6 percent in the morning and evening plans respectively. However, in this small network there are as many external links as internal; when all links in the five-intersection network are considered, the reductions in delay fall to 10.8 and 10.1 percent, respectively.

Estimated Benefits

The TRANSYT runs confirmed that reductions in delay as a result of coordination of signals diminish as the distance between signals increases. However, reductions in delay were still found to be significant over the range of road lengths (500-2000 m) examined.

On road links between 1000 and 1500 m long, reductions in delay of up to 20 percent were estimated with coordinated signal timings compared with uncoordinated control. Roads in this length range occur frequently in the arterial road network in Kuwait between the First and Fourth Ring Roads. A greater reduction in delay may be expected within Kuwait Town where link lengths are much shorter, but less improvement may be obtained on and beyond the Fourth Ring Road where distances between intersections are greater.

With the inevitable break in coordination on roads that span subareas that are operating on different cycle times, the overall network-wide reduction in delay will be less than that for individual coordinated links. The characteristics of the Kuwait road network are such that, at times, the number of different cycle times in operation may be greater than that in many coordinated traffic signal systems with a similar number of intersections. It was therefore considered that a network-wide reduction in delay of 10 percent represented a reasonable, conservative estimate of the improvements that could be obtained from the coordination facilities provided by a modern traffic signal system.

TABLE 8 Reduced Delay with Coordination on a Five-Intersection Arterial Network in Kuwait

Traffic Flow	Delay by Type of Signal (vehicle-hr/hr) Uncoordinated	Coordinated	Reduction in Delay (%)
7-8 a.m.			
Links internal to network	205.7	167.8	18.4
All links in network	350.7	312.8	10.8
5-6 p.m.			
Links internal to network	133.6	107.4	19.6
All links in network	258.4	232.3	10.1

SUMMARY

The work described previously, which was undertaken during a feasibility study of a traffic signal system for the city of Kuwait, demonstrated that platoons of traffic remain grouped over distances of up to 2000 m on the arterial and ring roads in the urban area. These roads are 6-lane divided roadways of high standard with little in the way of friction effects to disturb the smoothness of flow.

Measured rates of platoon dispersion were found to be equivalent to a TRANSYT platoon dispersion factor in the range of 30 to 50. Use of the TRANSYT model indicated that optimized signal timings are not sensitive to the value assumed for K in this range. Based on these observations, it was conservatively estimated that delays at traffic signals may be reduced by at least 10 percent through coordination of signals on the arterial and ring roads of Kuwait, where intersections are 1000 to 1500 m apart.

The results demonstrated that the distance between signalized intersections is not necessarily an adequate reason for disregarding the potential benefits of coordination. Where friction effects are small and platoons are readily identifiable as they approach the downstream intersection, coordination may be beneficial even over long distances.

ACKNOWLEDGMENT

The authors would like to acknowledge the assistance given by the staff of the Kuwait Municipality and other project team members in the work described in this paper.

Discussion

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Appropriate traffic coordination can guide the random traffic flow into a compact platoon, control travel speeds, and provide safe crossing gaps for efficient traffic operations. Platoon dispersion of vehicles that travel between signalized intersections can reduce the potential benefit of traffic

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signal coordination. This paper took a major step in analyzing the sensitivity of the platoon dispersion factor on the optimized traffic signal timing settings.

An interconnected signal system can result in a controlled nonuniform traffic flow during different signal cycles. If progression between signals is good, most of the traffic will arrive at the downstream intersection in a progression platoon during the green signal phase. This phenomenon can best be observed through the average arrival rate in the green phase, which is greater than the average arrival rate during the red phase. On the other hand, poor progression could result in a greater arrival rate during the red phase than that during the green. The percentage of an approach's through traffic coming from an adjacent upstream intersection and arriving during the through green at the downstream intersection depends principally on three factors: (a) percent of the total traffic that is in the progression platoon, (b) size and rate of platoon dispersion, and (c) quality of platoon progression between the two intersections. The percent volume progressed can be calculated from the product of (a) percent of the total through traffic in the arterial direction, (b) length of platoon leaving the upstream intersection, and (c) time period for the through movement saturation flow to clear at the upstream intersection in the arterial travel direction.

The platoon length that arrives at the downstream intersection depends on (a) the original platoon length that left from the upstream intersection, (b) the average travel time between the intersections, and (c) the number of vehicles in the platoon. The platoon dispersion rate increases with increasing travel time between intersections and small platoon size.

The progression quality of platoons between two intersections could best be described by the location and the amount of the through green time being used by the progression bandwidth. The period during which the progressed platoon occupies the through green at the downstream intersection depends on (a) the platoon length that arrives at the downstream intersection, (b) the length of the through green time at the downstream intersection, and (c) the progression quality between these two intersections. The optimal calculated arterial progression time-space diagram calculated can be used to examine the quality of progression between the intersections. Good progression would result in a larger progression bandwidth, whereas bad progression might result in either a smaller progression bandwidth or no progression bandwidth.

From this study and the similar research made by the Texas Transportation Institute under HP&R Study 2-18-80-293, supported by the Texas State Department of Highways and Public Transportation, the following comments may be made:

1. Platoon dispersion factors are affected by the approach speed of vehicles that enter and leave the studied intersections.
2. The use of upstream intersection control strategies can affect the progression platoon on the downstream intersection. Arterial traffic operations on high-speed, short-link roads tend to keep platoon travel together.
3. A periodic relationship was observed between the arterial specific link delay, and the ratio of travel time versus cycle length provides a better estimate of the arterial link delay than would the travel time alone.
4. Disutility or the resultant signal delay can be redistributed in the network by the platoon progressed between intersections. The adjustment of combining offsets and the green time to allow more favorable travel directions can further improve the efficiency of the traffic flow on arterial signal systems.
5. This study again raises the question of whether the intersections at certain distances can benefit from the time-based coordination.
6. What are the effects of platoon dispersion on the quality of progression? How valid is the bandwidth theory related to the progression efficiency as disturbed by the dispersion of platoon progressing through the downstream intersections? What is the best method for measuring progression quality that reflects platoon dispersion on signalized arterial networks?

Author's Closure

In summary, the theory that estimation of interconnect feasibility on the basis of link lengths alone is an oversimplification and that other roadway characteristics can be significant is confirmed in this study. Also demonstrated is the theory that use of the TRANSYT program's default value for the rate of platoon dispersion is adequate for a wide range of conditions. The majority of users need not, therefore, invest valuable data collection, time, and money in measuring platoon dispersion rates on their own road networks.

REFERENCES

1. D.I. Robertson. TRANSYT: A Traffic Network Study Tool. LR 253. U.K. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, 1969.
2. D.I. Robertson and P. Gower. User Guide to TRANSYT Version 6. SR 255. U.K. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, 1977.
3. P.B. Hunt and J.V. Kennedy. A Guide to TRANSYT/7. SR 595. U.K. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, 1978.
4. R.A. Vincent, A.I. Mitchell, and D.I. Robertson. User Guide to TRANSYT Version 8. LR 888. U.K. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, 1980.
5. TRANSYT-7F User's Manual. Release 3, Transportation Research Center, University of Florida, Gainesville, Feb. 1983.

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