Traffic Modeling Using Queueing Theory

"Prince Shaker Street Case"

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ABSTRACT

In this thesis, the problem of sequencing and setting interconnected traffic signals is addressed. Both analytical and numerical models exist for the single intersection problem. The objective is to improve the performance, that is measured in terms of total delay, by incorporating the inter-dependence of the successive signals. Hence, a method was developed for sequencing and timing of the interconnected signals to enable the use of an existing computer package, TRANSYT-7F, designed for finding the time setting of interconnected signals given the required sequence. The method developed in this thesis lead to improving the performance on a selected case study as well as decreasing the required computer time while providing good solution.

بسم الله الرحمن الرحيم

الخلاصة

في هذه الرسالة نناقش مسألة جدولة وتوقيت اشارات المرور المتعاقبة المرتبطة ببعضها البعض ، حيث يتوفر نماذج رياضية وعددية لحل مسألة جدولة وتوقيت الاشارة الواحدة . وتهدف هذه الدراسة الى تحسين مستوى الاداء على الاشارات المرتبطة مقاسا بوقت الانتظار الكلي على مجموع الاشارات على التقاطعات .

لقد تم تطوير طريقة لجدولة وتوقيت الاشارات المتعاقبة بحيث يمكن الاستفاده من حزمة برمجيات جاهزة (TRANSYT-7F) والمصممة لايجاد التوقيت الامثل على الاشارات لنظام جدولة محدد لهذه الاشارات ونتيجة لاستخدام هذه الطريقة فقد تم تحسين الاداء على الاشارات في حالة دراسية طبقت عليها هذه الدراسة بالاضافة الى انه امكن تقليل الوقت اللازم لاستخدام الحاسوب والمحافظة على جودة الحل الناتج .

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CHAPTER ONE

Introduction

1.1 Background:

Queueing theory is one of the most important fields of applied sciences that is widely used in a variety of areas such as computer systems, telecommunications, traffic and transportation engineering. The importance of Queueing Theory comes from its applicability and capability to solve real-life problems.

In this research, queueing models have been used to solve traffic problems, especially delay problem. The aspect of minimization of delay is important since it is directly proportional to fuel consumption and pollution of environment. When delay is minimized, more vehicles are allowed to pass a certain point of the road in a given period of time.

1.2 Study Area:

The area under study is **Prince Shaker Street.** A map of the area is shown in Fig 1.1. The principal reason for choosing this street is the existence on it of five inter-connected traffic signals. Because the goal of this study is to apply operations research methods, especially, the queueing theory and simulation, in order to schedule these traffic signals to have a smooth traffic flow, this street is considered suitable for case study. Other factors that affect the selection of this corridor are:

1) This area is one of the fast developing sections in Amman. This can be seen clearly from the large population that moved

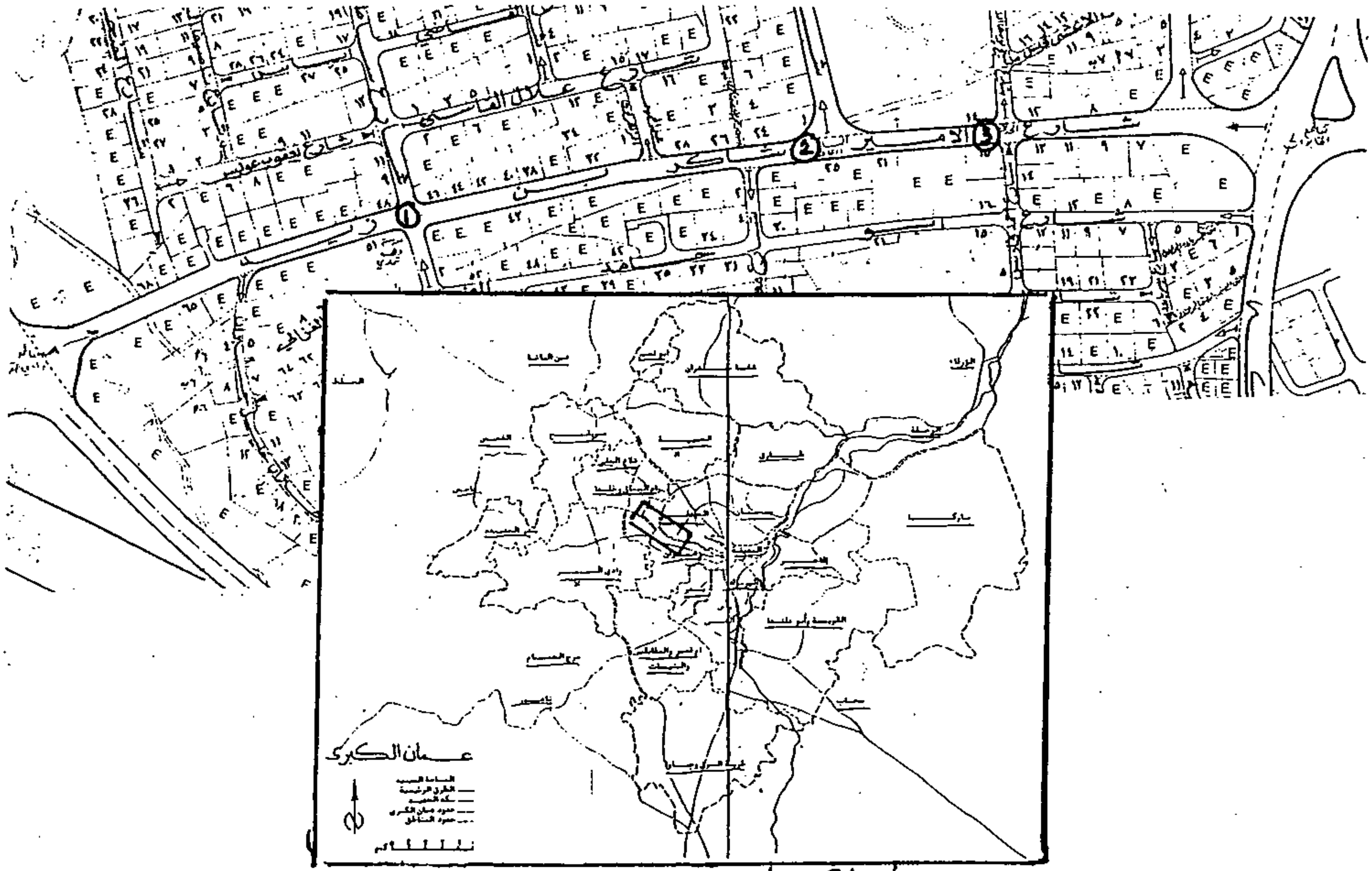

Fig 1.1 Map of area under Study

from other parts of Amman to this area.

2) Because of the traffic congestion in the center of Amman, which was a result of the increase in the number of vehicles, it was natural for many of the businesses to move outside the center.

3) Another characteristic of this area is the existance in it of some centers ot attraction, such as restaurants, banks, and governmental departments. These centers attract traffic.

4) This area is considered as a major link between several areas in Amman.

Because of all the factors listed, it is not unusual to find that this area has a high traffic volume. For this reason, traffic authorities, including Municipality of Greater Amman, found it necessary to change the geometry of several intersections in that area. An intersection is defined as the general area where two or more highways or streets join or cross each other. Within an intersection are included the roadway and roadside facilities for traffic movements in that area. One of the intersections in this area was previously an at-grade intersection, at which traffic intersects at the same level, was changed later to a multi level intersection -the Mukhabarat interchange-. Another intersection was up-graded from a circle to a signalized intersection, namely, Wadi Sakra intersection.

1.3 Objective:

The objective of the selected case is to study the traffic flow at Prince Shaker Street between Mukhabarat and Wadi Sakra Intersections, to determine how to get the traffic flow as smooth as possible. To achieve this objective, it is important not to have bottleneck points where traffic congestion occurs. Accordingly, taking into consideration all what has been discussed above, the problem on hand is to "**SET SIGNAL SEQUENCE AND TIMING FOR INTERCONNECTED TRAFFIC SIGNALS**". Stated differently, the problem is to schedule the separate intersections signal timing so as to eliminate the problem of congestion and delays in traffic flows.

Mathematical analysis and modeling, techniques of systems and control engineering, and computer simulation, are some of the methods that can be used in this problem. When it becomes evident that an intersection has become a bottleneck detrimental to the satisfactory operation of the adjacent highway system, a detailed study of its physical and operational capabilities and limitations must be carried out. Based upon the study, appropriate decisions can be made as to the nature and degree of improvement possible and justifiable.

Signal sequencing can be achieved by modeling the system as queues with service interruptions, which is one kind of queueing systems. Interruption at a given intersection means that traffic signal changes to RED, and a queue starts to build-up at the specified intersection.

Simulation is a powerful analysis and design tool. Once a simulation model is constructed, it acts as an experimentation laboratory in which the impacts of various design alternatives can be carefully evaluated.

The simulation technique has been used in the case this research is dealing with, and Queueing Models, which is the heart of simulation has been applied through a computer package known as TRANSYT-7F, which has a built-in traffic models that uses simulation. This research attempts to use anew algorithm to improve utilization of TRANSYT-7f procedure.

1.4 Overview of the Thesis:

In chapter two, a review of related literature is presented. Chapter three which is titled Research Methodology, included three main parts, the collected data that is needed in this research, the mathematical model that was tested in order to minimize delay, and the simulation technique used in order to find an optimal or near-optimal solution using a computer package named TRANSYT-7F. In chapter four, TRANSYT-7f was implemented and a new algorithm was developed in order to reach the solution in a very short time. Chapter five concluded the research and suggests some ideas for future research topics.

CHAPTER TWO

Literature Review

2.1 General

A number of researchers had investigated problems associated with intersections such as delay of vehicles, and queue at the up-stream of the intersection (the in-coming traffic). Some of those researchers used conventional methods to solve intersection problems like Webster and Pignataro. Others tryed to find some new measures that could be used and give global solutions as Shanteau and Taylor. In the following sections, the methods used to solve the problem of congestion and minimizing delay.

2.2 Webster's Formula(1,2,3)

Webster has developed the following approximate formula for determining the optimum cycle length in terms of minimum delay:

$$C_o = (1.5L + 5)/(1 - \sum y_i) \text{ ....(2.1)}$$

where, C_o = optimum cycle length, seconds

L = lost time, seconds

y_i = design flow/saturation flow

The above formula is a simple approximation of a more complicated relationship. In this method, all, or nearly all, of the amber time is assumed to be usable for vehicle movement. To start with, the conflicts between streams are prevented by a separation in time for the different traffic movements. The procedure by which the streams are separated is known as Phasing the Traffic. Each phase should not have any intersecting (conflicting) traffic. The number of phases employed at any intersection should be kept to a minimum. In Jordan, left-turns on red are prohibited. So, the left-turners could not turn between gaps of the opposing traffic. Therefore, a special phase for left-turn movements is to be introduced.

The capacity of approach, which is the leg of intersection having traffic movement, is affected by two factors, geometric and traffic factors. These two factors are discussed below.

2.2.1 The Geometric Factor

This factor includes lane width, gradient, and radius of turning movements. The saturation flow, which is the flow in vehicles per hour which would be obtained if there was an infinite queue of vehicles and given a 100 per cent green time, is an important factor in designing the intersection, since it is dependent on geometric parameters. For the unopposed traffic streams, the saturation flow is given by:

$$S_1 = (S_o - 140d_n)/(1 + 1.5 f/r) \quad \text{..........(2.2)}$$

where,

S_1= saturation flow for unopposed streams, pcu

S_o= $2080 - 42d_g * G + 100 (w - 3.25)$

d_n= is 1 for nearside lanes and 0 for non-nearside lanes

d_g= is 1 for uphill entries and 0 for downhill entries.

f = is the proportion of turning vehicles in the moving traffic lane

r = is the radius of curvature of vehicle paths, meters

G = is the percentage gradient for the entry lane

w = is the lane width at entry, meters

For opposing traffic streams (which is not considered in Jordan), saturation flow S_2 is given by

$$S_2 = S_g + S_c \text{ .... } (2.3)$$

where, S_2= saturation flow for opposing streams

S_g= is the saturation flow in lanes of opposing mixed turning traffic during the effective green period (pcu/hr)

S_c= saturation flow in lanes of opposed mixed turning traffic after the effective green period (pcu/hr).

2.2.2 The Traffic Factor

This is the second factor that affects the approach. This is mainly introduced by the use of weighting factors, referred to as passenger car units ,pcu's, which is a representation of larger vehicles, such as trucks and buses, as equivalent to a number of passenger cars to be used in Level of Service and capacity analysis. The magnitude of the equivalency is dependent upon vehicle size and weight, vehicle operating characteristics, vehicle speeds, and roadway characteristics, such as gradient. Important traffic factors that affect capacity of the approach are:

1) Determination of effective green time. This factor indicates the number of vehicles that could cross a stop line over the whole cycle, comprising red, green, and yellow (or amber) intervals.

2) Lost time occurs due to starting delays, while some vehicles cross the stop line during the amber interval either before or after the actual green phase. This measure, lost time, is considered in design of capacity. It can be calculated as shown in the following formula:

Effective green time= actual green interval + amber interval
- lost time.......................(2.4)

3) Cycle length. In order to find the optimum cycle length, a new measure is defined. The y-value, which is the flow on the approach divided by the saturation flow, is a measure that gives an indication about how green time should be split. Then, the sum of the maximum y-values for all approaches , Y, is considered in finding the optimum cycle length, C_o. This is found experimentally by simulation of flow at different traffic signals as shown in equation:

$$C_o = (1.5 L + 5)/(1 - Y) \quad ....(2.5)$$

This optimum cycle length would result in minimum overall delay when employed with fixed time signals and should result in waiting vehicles clearing the intersection. Then, the effective green time is divided by the phases in the ratio of the y_{max} of each phase.

The effective green period could not be taken simply as measured. It depends also, as stated earlier, on the geometric factors of the approach. For example, when the width of approach is wide, the effective green for that approach could be recalculated taking into consideration the saturation flow, actual flow, and approach width.

The length of queue at any approach at the beginning of the green period could then be found easily. Two cases are possible:

a. <u>Unsaturated green period:</u> where the queue disappears during the green period before the green signal phase changes to amber. The following equation finds the number of vehicles in the queue:

$$N_u = q\ r \quad ....(2.6)$$

where, N_u = initial queue at the beginning of the unsaturated green period, pcu

q = flow (pcu/sec)

r = effective red (sec)

b. <u>Saturated green period:</u> where, the queue builds up and does not disappear before the start of the amber interval. In this case, the delay is a major element in order to find the length of queue that should be considered, as in the following equation:

$$N_s = \max \left\{ q\left(\frac{r}{2} + d\right)\left(1+ \frac{qj}{av}\right) \quad , \quad qr\left(1+ \frac{qj}{av}\right) \right\} \quad (2.7)$$

where,

N_s = initial queue at the beginning of a saturated green period, pcu

q and r= as defined previously

d = average delay per vehicle (sec)

a = number of lanes in queue

j = average spacing of vehicles in queue

v = free running speed, m/sec

As mentioned before, this method was developed mainly under the assumption of getting minimum delay. The average delay per vehicle on a particular intersection could be calculated as follows:

$$d = cA + (B/q) - C \quad \ldots\ldots\ldots\ldots\ldots\ldots(2.8)$$

where, d= minimum delay, sec

c= cycle length, sec

A= $(1-\lambda)^2/2(1-\lambda x)$

B= $x^2/2(1-x)$

C= $0.65(c/q^2)^{1/3}x^{(2+5\lambda)}$, correction factor

λ = proportion of cycle that is

effectively green

x= degree of saturation "$q/s\lambda$"

q= flow, pcu/sec

This average delay per vehicle is used to find the total delay (D) for the intersection as follows:

$$D = \sum(\text{average delay per veh.}) * \text{flow} \quad .....(2.9)$$

By differentiating this total delay with respect to cycle time C, and setting the derivative to zero, the optimum cycle length, C_o, is then as follows:

$$C_o = 2LF/1-Y \quad ....(2.10)$$

where, L = total lost time per cycle

$$F = 1 + \frac{\sqrt{[Y^2 - Y + 1/E] - Y}}{2}$$

$$E = \frac{L(1+Y)^2}{16\ n\ Y^5} \sum_{1}^{n} \frac{y_r\ S_r}{1-y_r} \left[4(Y-y_r)^2 - y^2(1-Y)^2\right]$$

Y = y_{max} over all phases, which is the ratio of design flow to the saturation flow

2.3 Pignataro's Method [1,3]

Pignataro has suggested a method that is used widely nowadays in the signalization of intersections. In this method, the first step is the phasing of traffic.

Intersections of more than four approaches may require a division of the cycle time into more than two phases, which, in general, should be avoided, since each additional phase lengthens the overall cycle. This may result in increasing delay.

In this method, for the timing of traffic signals it is extremely desirable to consider the variation in traffic flow during the peak hour. A peak 15-minute period is considered to be the shortest practical time to express this variation. The peak hour factor (PHF) is defined as the ratio of vehicles entering the intersection during the peak hour to four times the number of vehicles entering during the peak 15-minute period. Left turning vehicles and commercial vehicles require more green time than do straight or through passenger cars. One method of addressing this problem is treated in the following paragraph.

The procedure used in this method to account for the determination of commercial vehicles, and turning movements on the time of start up, or average headway, in the determination of cycle time, is to convert the demand volume, given in mixed vehicles per hour with percentage of commercial vehicles and left-turns (which is not considered here in Jordan), to an equivelent volume in straight passenger cars. This procedure develops passenger car equivelent (pce) for all demand volume. Under this procedure, each non-left turning passenger car is equal to 1 pce each. Buses and trucks are assumed to be each equal to 1.5 pce. This is based on the finding that each left-turn movement consumes 1.3 seconds of additional time.

Since the minimum departure headway is 2.1 seconds, it can be shown that:

$$1 \text{ left-turn} = (2.1 + 1.3)/2.1 = 1.6 \text{ pce}$$

Vehicle clearance interval, which is the required sufficient time for vehicles to clear the intersection before cross traffic starts to move, is a very important measure that is considered in the sense it incorporates a safe stopping distance. The Traffic Engineering Handbook(9) recommends the following formula:

$$Y = t + \frac{V}{2a} + \frac{(w + l)}{V} \quad \text{..............(2.11)}$$

where, Y= clearance interval, in sec

t= perception-reaction time, in sec, suggested value = 1.0

V= approach speed of clearing vehicle, in ft/sec

a= deceleration rate of clearing vehicle, in ft/sec^2, suggested value = 15

w= intersection width in ft

l= length of vehicles in ft, suggested = 20

This formula is based on a coefficient of anti-skid friction of about 0.5.

The goal of Pignataro's method is finding the appropriate cycle length. In general, the calculated minimum cycle length will be checked against the following requirements:

$$C_{min} = \frac{Y_i}{1 - [\ N_iS_i/3600(PHF)]} \quad ....(2.12)$$

where, C_{min}= minimum cycle length, seconds

N_i= critical lane volume, the number of vehicles in a single lane entering the intersection during the peak hour, pce.

S_i= approximat average headway between vehicles entering the intersection

Y_i= vehicle clearance interval in sec

PHF= peak hour factor

This minimum length is split between the different phases in proportion to the relative critical lane volumes. The green time for each approach is checked. Cycle failure is addressed indirectly by requiring that the peak 15-minute volume for each leg be accomodated in the green time available to that leg in the peak 15-minutes; that is, it is required that, for all approaches,

$$\frac{N_iS_i}{4(PHF)} < \frac{900}{C} G_i \quad ....(2.13)$$

where, N_i and S_i= as defined previously

PHF = peak hour factor

C = cycle length, seconds

G_i= available green time for phase i

constant 900= number of seconds in 15 minutes.

2.4 Shanteau's Method(4)

Shanteau developed a new method for measuring the saturation flow and lost time. This method depends mainly on constructing some curves. The importance of the saturation flow comes from the fact that the number of vehicles that cross the intersection in the green phase is dependent upon green interval. Previously, the number of vehicles were calculated using the following equation:

$$N(t) = s\ (\ t - L_s\ )\ \ldots\ldots\ldots\ldots\ldots(2.14)$$

where, s = saturation flow, vph

t = time that allows vehicles cross the intersection, seconds

L_s= starting lost time, seconds

The new method presented by Shanteau assumes that the number of vehicles to enter the intersection in one phase is not simply N(G), where G is the green time, because vehicles continue to enter for some time after light turns yellow. The amount of yellow time (Y) that is effectively unused is the ending lost time L_e, so the number of vehicles to enter in one saturated phase of length G+Y is:

$$N(G+Y) = s\ (\ G + Y - L_s - L_e\ )\ .....(2.15)$$

and, if the total lost time is $L_s+L_e = L$, then

$$N(G+Y) = s\ (\ G + Y - L)\ \ ....(2.16)$$

By calculating the number of vehicles which have cleared the intersection, the number of vehicles that are still in the queue at the signalised intersection can be determined.

2.5 Taylor, et al Approach (5)

In their paper titled "**Queue volume: a measure of congestion**", Taylor, et al used a new approach for identifying the traffic performance. This approach mainly uses the traffic detector data to identify the congested situations. The new measure is named the "**degree of congestion**". In some previous work, the queue length was considered. It seeks to minimize the sum of the queue lengths on each arm of an intersection or over a network. In another work, the "free capacity" on the link , which is the difference between the link length and the queue length, was considered as a measure of traffic congestion. The new measure of congestion developed by Taylor is the "**Queue Volume**". This measure is based on the level of queueing, and on the length of time a queue persists. The advantage of this measure is that it provides a time dimension reflecting the proportion of the cycle for which a given queue was at or close to the maximum. This means that when the maximum queue is equal to the link length, queue volume continues to increase. However, queue volume is a better estimator than maximum queue length, particularly at periods of high delay. This measure was tested against traffic density and vehicle time-of-occupancy, and high a correlation was found. As a result of this study, and because this measure gives a time dimension to the queue length, it represents the true behaviour of traffic flow more accurately than the existing methods using queue length. Finally, queue volume should be considered in improving the operation of vehicle-responsive signal control.

2.6 Lin's et al Findings(6)

Lin et al pointed out the three basic requirements that should be satisfied by a queue dissipation model developed for simulation analysis of signal operations. First, the model should provide a realistic representation of the probabilistic characteristics of queue discharge times or headways. Second, after the green onset, queued vehicles will enter and occupy a specified space in the approach lane for different lengths of time. The model should provide a realistic representation of the probabilistic characteristics of such dwell times. And, finally, the model should be sufficiently flexible that it can be conveniently calibrated for varying conditions.

In his study, Lin used a simple car-following model to reproduce queue dissipation characteristics. In this model, the following assumptions are made:

(1) A driver would assume that at any instant the vehicle immediately ahead has the possibiltity of decelerating at a

rate E and coming to a stop.

(2) a driver would adjust the vehicle speed continuously so that an acceptable deceleration rate KE can be applied to achieve a safe stop if the vehicle ahead decelerates at the expected rate E and comes to a stop.

Based on these assumptions, the driver behaviour can be represented as:

$$B = \frac{-(2V_2 - hKE) + Q}{2h} \quad ....(2.17)$$

where, B= constant rate of speed change of following vehicle

V_2= speed of the following vehicle E = deceleration rate of vehicle 1, ≤ 0

K = a positive constant representing the degree of risk a driver is willing to take

h = a small time interval

The inputs to the simulation model include the following traffic charateristics: vehicle length, vehicle type, driver reaction time in response to the green onset, speed, and spacing between stopped vehicles. This study concluded that the driver reaction time can assume a constant value. The length of each vehicle does not have to be treated separately. Instead, the average length of each vehicle type (passenge cars, trucks, busses, etc) could be taken to represent the lengths of individual vehicles. The spacing between stopped vehicles can be represented by a constant value. The probabilistic nature of steady state speeds and the variations of the K factor due to behavioral differences among drivers should be considered well.

2.7 Srikar and Vinod's Method(7)

Srikar and Vinod constructed a closed queueing network performance model at American Airlines to evaluate the performance of large complex flow shops. This model, which was named **QNET**, estimated the performance and capacity of job shops using a network of queues models. The reason of using these queues models is three-fold: (1) extensive data for simulation is needed, (2) violation of theoritical assumptions, though queueing networks proved to be good tools to deal with such situations, (3) simulation models are time consuming, so, queueing models proved to be ideal.

QNET model, although it is built mainly to find the capacity and performance of a landing gear shop, it can be applied in the traffic modeling for the following reasons:

1. the model consists of a closed queueing network with a finite number **M** of work stations (traffic signals are considered as work stations)
2. first-come-first-served (FCFS) or infinite-server (INFS) queue disciplines can be simulated (FCFS, could simulate the queue before the traffic signal if the signal is red. INFS, could simulate the transit time on the road between two traffic signals)
3. each work station i may have one or more identical

machines, c_i, with a service time distribution that is exponentially distributed (each intersection has four legs -approaches-, and each approach has three movements, through, left, and right turn. Each movement could be considered as a machine c_i)

4. jobs that have distinct process plan are classified as a distinct job class. R job classes with distinct work-in-process (WIP) levels are considered in this model (each vehicle type -bus, car, truck ...etc- could be considered as a job class. Clearance time of the vehicle -time to cross the intersection while the signal is green- could be considered as the WIP time)
5. the needed data to process each job is and (variance and mean)
6. concerning memory requirements, **QNET** was tested and found accurate for large problems, M=50 and R=200 (maximum of 50 traffic signals and 200 of vehicle types)
7. breakdown and repair of unreliable work stations are allowed in this model (breakdown represents a red signal, and service represents a green signal)

The output of **QNET** model is very important in so many ways. It echoes the input data: the work station summary, the process plans and work load summary by part type. The performance characteristics about the system are provided also. These performance characteristics are:

1. average queue length. This measure could point the minimum total delay concerning the intersection

2. average waiting time (including service)
3. utilization, which can give a clear idea about the usage of green signals
4. identify bottleneck stations, where this can point the intersections that are considered as a bottlenecks.

CHAPTER THREE

Research Methodology

The mathematical model which is represented by Webster's equation has been investigated in order to figure out if it can be applied on the case of Prince Shaker street. Then, a simulation and optimization tool has been used to describe the flow of traffic as a function of signal phasing and then find an optimal or near-optimal solution to the case we are dealing with. Data for the current flow in Prince Shaker Street has been collected.

The following reasearch stages have been done:

3.1) Data Collection:

Traffic data were collected at the different intersections considered in this research as shown in Fig 1.1. Data consisted of the traffic counts for each direction an for each movement, i.e. left and right turns and through traffic. Data collected consist also of the existing signal phasing for the different periods. The distance between each intersection, and the average running speed of vehicles are known (see Fig 3.1).

Traffic data were taken from the Municipality of Greater Amman. It includes the traffic counts at each single intersection. These data were taken each 15-minute period. Counts were taken for the morning peak from 7:30 until 9:30 a.m. Data were also taken for the off-peak period where the traffic was counted from 12:00 until 2:30 in the afternoon. For a third period, which is the evening peak, traffic was

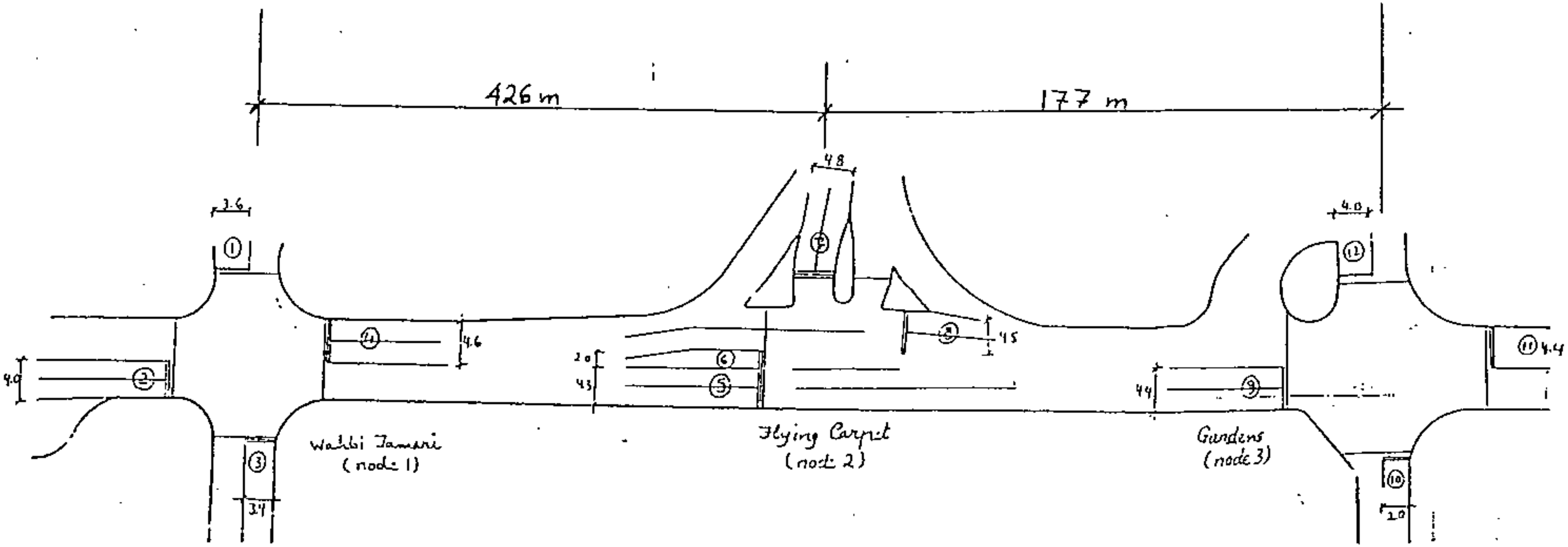

Fig 3.1 Layout of intersections

counted from 4:00 until 6:00 p.m.

The collected data were not considerd sufficient. So, further counts were made in order to find the turning movements, which are of great importance, since they affect the phasing and timing of each signal, and also, they affect delay, which is an important issue in finding the optimal cycle length. All data are shown in Appendix C.

3.2) Mathematical Model:(1,2)

As can be seen from the literature review, many researchers discussed the issue of traffic flow under certain conditions such as vehicle delay, formation of queues, non-smoothness of flow, and congestion.

The delay model that was developed by Webster has been tested in order to find delay, which is the major factor that affects the cycle length. In Webster's model, the optimum cycle length C_o would result in minimum overall delay when employed with fixed time signals, such as in the case we are dealing with. The average delay per vehicle on a particular arm is given by:

$$d = \frac{c(1-\lambda)^2}{2(1-\lambda x)} + \frac{x^2}{2q(1-x)} - 0.65\left(\frac{c}{q^2}\right)^{1/3} x^{(2+5\lambda)}$$

where, d = average delay per vehicle, sec

c = cycle time, sec

λ = proportion of the cycle that is effectively green for the phase under consideration, g/c

q = flow, veh/sec

s = saturation flow, veh/sec

x = degree of saturation, which is the ratio of actual flow to the possible flow "effeciency" it equals to $q/s\lambda$

3.2.1 Calcualtion of Delay:*

Using the above equation, and using the signals phasing of Prince Shaker Street that is introduced from the Municipality of Greater Amman, delay was found. The following tables present the results achieved.

Table 3.1 Tabulation of data taken from Municipality of Amman for Prince Shaker Street, seconds.

SIGNAL	ACTUAL GREEN	AMBER RED	AMBER	ALL RED	EFFECTIVE GREEN	RED
1	12	1	3	1	16	83
2	33	1	3	1	37	62
3	13	1	3	1	27	72
4	22	1	3	1	26	73
5	56	1	3	1	60	39
6	23	1	3	1	27	72
7	34	1	3	1	38	61
8	28	1	3	1	32	67
9	43	1	3	1	52	47
10	19	1	3	1	23	76
11	43	1	3	1	52	47
12	23	1	3	1	27	72

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* Appendix B contains a program that calculates delay using Webster's method

Table 3.2 Calculations of the different variables of delay equation

Signal	Width (m)	S Veh/H	s Veh/S	Flow Veh/H	q Veh/S	g sec	λ g/c	λs	x
1	3.6	1900	0.528	340	0.094	16	0.16	0.084	1.118
2	4	1950	0.542	1193	0.331	37	0.37	0.200	1.653
3	3.4	1880	0.522	321	0.089	27	0.27	0.141	0.632
4	4.6	2250	0.625	637	0.177	26	0.26	0.163	1.089
5	4.3	2075	0.576	854	0.237	60	0.6	0.346	0.686
6	2	1100	0.306	360	0.100	27	0.27	0.083	1.212
7	4.8	2420	0.672	819	0.228	38	0.38	0.255	0.891
8	4.5	2215	0.615	475	0.132	32	0.32	0.197	0.670
9	4.4	2150	0.597	1402	0.389	52	0.52	0.311	1.254
10	2	1100	0.306	307	0.085	23	0.23	0.070	1.213
11	4.4	2150	0.597	877	0.244	52	0.52	0.311	0.784
12	4	1950	0.542	517	0.144	27	0.27	0.146	0.982

Table 3.3 Delay for each approach using Webster's equation, seconds

Signal	Uniform	Random	Empirical	Delay
1	42.96	-56.34	19.940	-33.32
2	51.009	-6.32	43.650	1.039
3	32.13	6.09	3.230	34.99
4	38.19	-37.64	12.670	-12.12
5	13.59	3.16	1.190	15.56
6	39.61	-34.64	26.650	-21.68
7	29.05	15.97	5.150	39.87
8	29.42	5.15	2.750	31.82
9	33.11	-7.95	16.030	9.13
10	41.12	-40.63	28.660	-28.17
11	19.45	5.83	2.520	22.76
12	36.26	186.02	10.330	211.95

3.2.2 Total Delay of the Intersection:

In this section, total delay will be calculated using the method described in **Road Research Technical Paper 39.** The total delay for the intersection is given by:

$$D = \sum (\text{average delay/vehicle}) * \text{flow}$$

So, using this equation, and using the aforementioned data, total delay for each intersection is found to be as follows:

$D_{Wahbi} = -1.79$

$D_{Flying} = 14.81$

$D_{Gardens} = 36.17$

From the previous tables, it can be seen that there are some delay values that have negative signs. In order to understand this situation, Webster's equation will be analyzed.

As it was stated before, delay "d" depends mainly on the effective green and saturation flow, considering constant cycle time and flow. Saturation flow, s, of the approach, is the uniform departure of traffic in a specific lane depending mainly on many factors. Some of these factors are: lane width, grade of the approach, existence of a parking lane, a bus stop, and pedestrian crossings. On the other hand, effective green time of an approach depends mainly on the traffic flow on that approach. Also, it depends on the y-value, i.e. the ratio between design flow and saturation flow, which in turn depends on saturation flow. The term "degree of saturation", which is dependent on flow, saturation flow, effective green, and cycle length, should not exceed unity. This is because it represents effeciency. In our case, it was found that some approaches have a degree of saturation, x, greater than unity. This can be explained in many ways. First, since as stated before, saturation flow depends on lane width, more than one vehicle occupy that width. This means that this lane releases more vehicles than it was designed for. Second, the green of the signal at such an approach is not phased adequately. In other words, green time is not enough to clear that specific approach. Finally, the traffic behaviour which the equation considered is not the same in Jordan. So, a new equation, or a correction factor needs to be added in order to suit existing traffic behaviour.

Another way of tackling the case is the Simulation technique. This has been used. A full description is presented in the next section.

3.3) Simulation Technique:(8,9,10)

As it can be seen from the mathematical model that had been tested, calculations of delay using Webster's model showed unreasonable values since there were some negative values. Webster's model is plotted in Fig 3.2.

It can be seen that, as the degree of saturation approaches and then, exceeds 100%, the model is not applicable. In common uses, the model is only considered valid for a degree of saturation up to about 95%.

There are many factors that affect delay; among them are:

1) Physical factors, such as the number of lanes, grades, approach width, access control, channelization and transit (bus) stops.

2) Traffic factors, such as volume on each approach, turning movements, vehicle classification, driver characteristics, approach speed, parking and number of pedestrians.

3) Traffic controls, such as types and timing of signals,

stop or yield signs, and turn and parking controls.

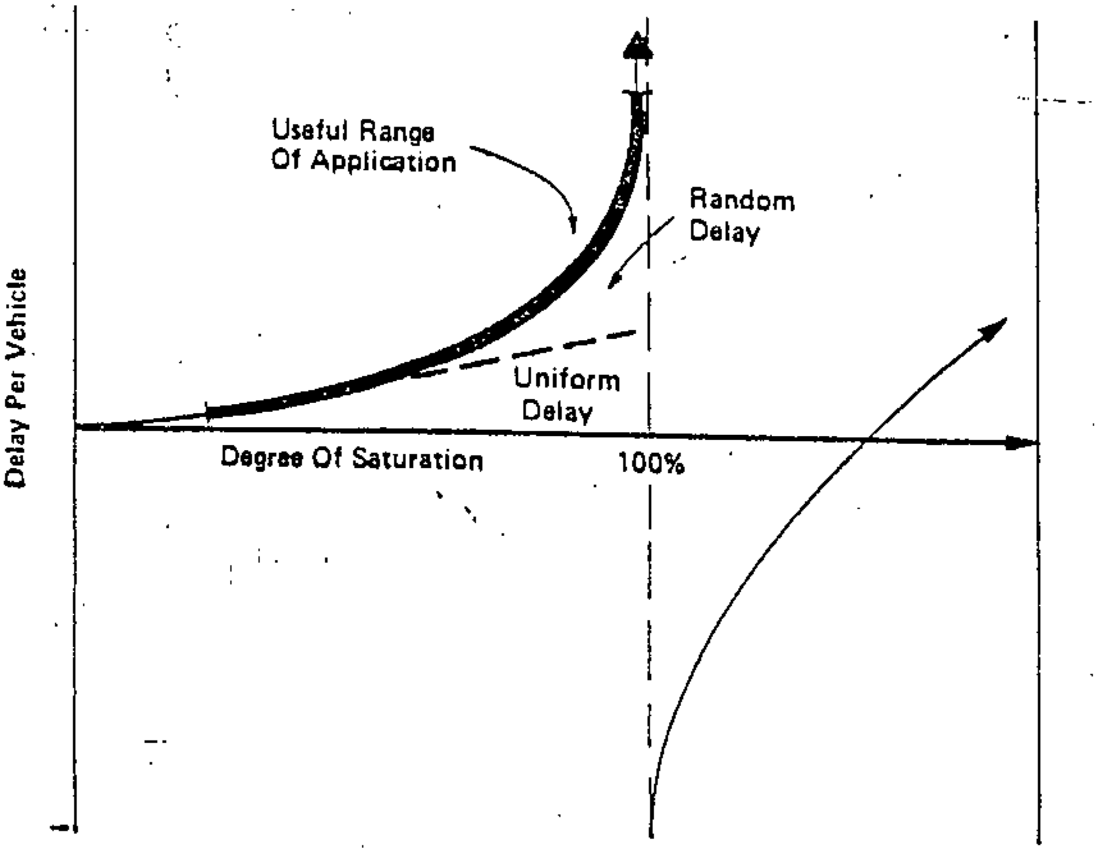

Fig 3.2 Webster's delay model

(Source: TRANSYT-7F, User's Manual, Rel. 6, 1988)

As it was stated before, the objective of this research is to "Set Signal Sequence and Timing for Interconnected Traffic Signals". This means that there should be a cycle length that gives a good performance to the system, and though, minimum delay, which is the most important factor that affects driver behaviour in terms of respecting traffic control, and in terms of comfort of driver. This can be achieved in different ways. Among these, vehicle can travel and cross different intersections with either no or minimum stops. So, a perfect progression, which allows no stops, is the case which provides largely non stop operation, with flow rates approaching 2000 passenger cars per hour of green per lane. This type of operation can be attained where there are relatively few turning movements, with all signal cycles being very close to fully loaded, and with no mid-block frictional elements. It is succeptible to abrupt breakdown whenever any abnormality in the traffic flow develops.

In order to reach a smooth traffic flow in the system, and because delay is a major issue that affects the smoothness of flow, and because the factors that affect delay are too complicated, especially when the saturation flow exceeds 95%, where Webster's Model cannot handle the problem, it can be seen that the most appropriate method to deal with the existing situation we are studying (Prince Shaker Case) by the use of SIMULATION.

Two existing computer packages have been tested in order to find the most suitable one that can handle the case. These packages are GPSS-PC, and TRANSYT-7F. A brief description of each of these packages would be of great importance in the selection of the most suitable package.

3.3.1 GPSS-PC(11,15)

GPSS is a simulation programming language, used to build computer models for discrete-event simulations. GPSS contains special features for reproducing the dynamic behaviour of systems which operate in time, and in which changes of state occur at discrete points in time. GPSS needs the analyst to build his/her own model using the blocks and statements built-in this language. This package had been tested on a small case. When it was compared with TRANSYT-7F (will be discussed later), it was found that TRANSYT-7F would be much more useful since it has the option of simulation and optimization, and was tested in many placed and found sufficient.

3.3.2 TRANSYT-7F[8,12]

TRANSYT-7F is one of the most popular traffic flow analysis and signal timing programs. This program optimizes the signal settings to reduce fuel consumption, delay and vehicle stops. This program, TRANSYT-7F, has two major functions, Simulation of traffic flow and Optimization of traffic signal timing plans.

1) The first major function, simulation of flow of traffic in a signalized network, is an analytical process that attempts to represent real world events. The traffic flow model in TRANSYT is among the most realistic models in many ways. This model considers platoons of vehicles rather than individual vehicles. Also, its representation of traffic is more detailed than other models because it simulates traffic in small time increments. This model utilizes a platoon dispersion algorithm that simulates the normal dispersion of platoons as they travel downstream. Another important consideration is that it considers traffic delay, stops, fuel consumption, travel time and traffic signal timing plans.

2) The second major function of TRANSYT-7F, is the development of an optimized traffic signal timing plan. TRANSYT optimizes phase length. To determine the best cycle length, an evaluation of a specified range of cycle lengths

may also be made. When optimizing, TRANSYT-7F minimizes an objective function called Performance Index (PI). The PI is either a linear combination of delay (where TRANSYT-7F bypasses the problem of degree of saturation when it exceeds 100% as shown in Fig 3.3), stops, and (optionally) excessive maximum back of queue, or excess operating cost.

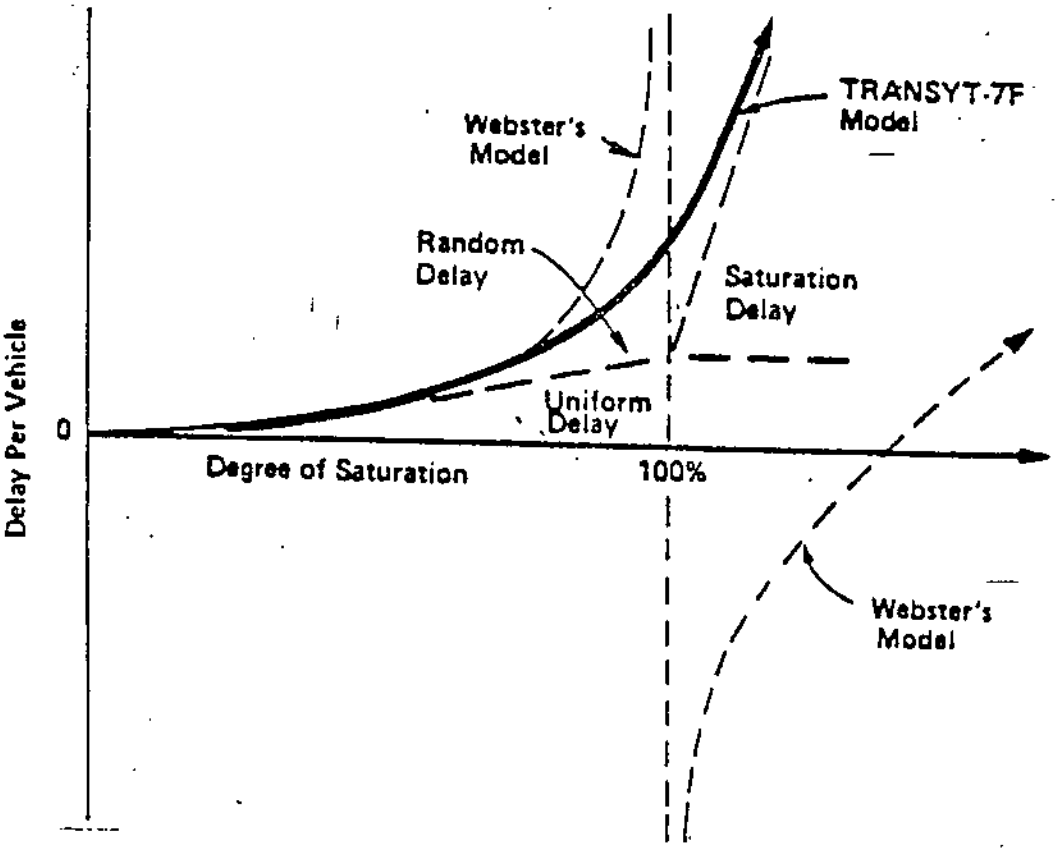

Fig 3.3 TRANSYT-7F estimate of delay

(Source: TRANSYT-7F, User's Manual, Rel. 6, 1988)

The delay/stops PI is defined as follows:

$$PI = \sum \{(w_{di}\ d_i + Kw_{si}\ S_i) + u_i(w_{di-1}\ d_{i-1} + Kw_{si-1}\ S_{i-1}) + B_i\ (W_q\ [q_i - c_i]_2)\}$$

where, d_i = delay on link i in vehicle-hour (and i-1)

K = a user input coefficient to express the importance of stops relative to delay

S_i = stops on link i (and i-1) in stops/sec

w_{xi} = link specified weighting factors for delay (d) and stops (S) for link i (and i-1)

B_i, u_i = binary variable associated with card type 34 (used by TRANSYT)

W_q = network-wide penalty applied to the excess queue "spillover"

C_i =maximum back of queue "capacity" for link i

From the previous discussion, it was concluded that TRANSYT-7F program is the most suitable package to use for this study.

3.4 Methodology of TRANSYT-7F:(8)

As it can be seen from the previous section, TRANSYT-7F appears to be a good tool that could be used to analyze the case we are dealing with. In this case, three intersections are located apart, in an area that shows some sort of congestion as shown in Fig 1.1. In the peak times, and in many cases, the signal timing plan cannot clear the intersection.

In order to analyze the case and to find an optimum solution, the following requirements are of great importance

1) General requirements before starting the analysis
2) Data collection requirements
3) Optimization requirements

3.4.1) General Requiremenets:(18,20)

As it was stated in the main objective, the goal of this study is to set a signal timing plan and a phase sequence. This implies two-fold criteria, first is to find the plan that gives a minimum system-wide operational delay and fixed delay.

Operational delay can be defined as that delay caused by interference between components of traffic, that is, delay due to influences of other traffic. One type of operational delay is caused by other traffic movements that interfere with the stream of flow (side frictions). This includes parking or unparking vehicles, pedestrians, stalled vehicles, double parking, and cross traffic. A second type of operational delay is caused by interferences within the traffic stream (internal friction). This includes congestion due to high volumes, lack of roadway capacity, and merging or weaving maneuvers.

Fixed delay, which is the second type of delay that affects the system, is the delay caused by traffic control devices. It is the delay to which a vehicle is subjected regardless of the amount of traffic volume and interference present, and it occurs primarily at intersections. It may be caused by traffic signals, stop signs, yield signs, and any other control device.

The second point of the criteria is the cycle length constraints. These constraints are very important since they are very much related to the signal plan. The following are some of these constraints:

a) the cycle length must be long enough to provide sufficient minimum times for all phases considering both vehicle and pedestrian requirements.

b) the cycle length should be sufficiently long to ensure that no movement is saturated, if possible. That is, the degree of saturation should be less than 100% for all approaches, at all intersections. This constraint results in a higher value for cycle length than does the previous one.

c) the cycle length should not be so long as to cause unacceptably high delays. In some studies, the maximum cycle length at which the user starts not to respect the signal was shown to be 120 seconds.

d) in a progressive system, the cycle length should be chosen to facilitate traffic progression.

3.4.2) Data Requirements:

The data required for running TRANSYT-7F is shown in Table(3.4).

Traffic data which concern the volumes and timing plan are taken from the records of the Municipality of Greater Amman. Turning movements, on the other hand, were not included. Therefore, 15-min counts were conducted in order to figure the different movements on each approach.

Table 3.4 Summary of input data requirements to run model

Major Category	Data Types
Network Data	- Nodes (intersections) - Links (streets) - Link distances (stopline to stopline) - Turning restrictions
Timing Data	- Existing cycle lengths - Existing offsets - Existing interval durations and phase lengths
Saturation Flow	- Saturation flow
Speed Data	- Cruise speed on links
Volume Data	- Total volume counts - Turning movement counts - Link-to-link movements

(Source: TRANSYT-7F, User's Manual, Rel. 6, 1988)

This short count is justified as Pignataro states: "in many cases, manpower, time, and financial limitations may rule out the feasibility of taking long counts. Manual counts have an advantage over machine counts in that the manual counts give classification and turning movements. The short count method involves counting for periods of 5,6,10, or 12 minutes at each location or intersection."

Input Data:(8)

Data required to run TRANSYT-7F can be summarized in the following steps:

1) Each intersection is represented as a node, and each movement at this node is considered as a link as shown in Fig 3.4. Each node in the network is given a number, and the same thing is done with links.

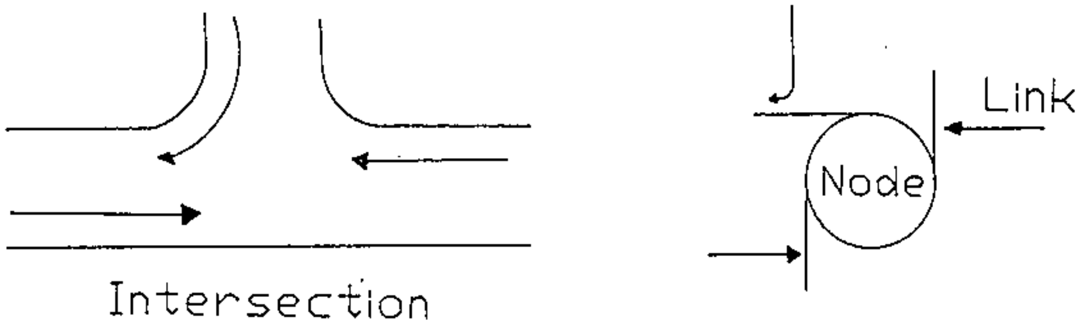

Fig 3.4 Representation of a node

2) Saturation flow for each link is figured out. The following table shows the effect of approach width on saturation flow

w (ft)	10	11	12	13	14	15	16	17
s(pcu/h)	1850	1875	1900	1950	2075	2250	2475	2700

Values in this table are given by the following equation:

$$s = 160 \ w \ \text{pcu/hr}$$

There are some correction factors that affect saturation flow, but we are not interested in them because non of them applies to the case we are dealing with.

3) The link length, which is the length between stop lines of two following intersectins is measured.

4) Timing plan and sequence for each intersection is figured out. These data are referred to the existing (installed) plan. The timing plan should add-up to the cycle length that is installed.

5) Average speed could be found by spot speed studies. In the case we are dealing with, the average speed is considered to be 35 Km/hr, since the design of the progression system that is installed assumes this value of speed.

6) Traffic counts for each intersection were taken each 15 minutes. The period that we are interested in for the study is the morning peak hour, between 7:30 a.m. and 8:30 a.m.

   Because the turning movements are an important issue in the analysis, and since the available counts do not include all the movements, additional counts were made to find out the percentages of turning movements to the total volume. Approach volumes are split into their components: through, right turn, and left turn movements.

7) Design hourly volume is found by figuring out the maximum half-hour volume of each approach multiplied by two.

8) Components of volume of each link are found -i.e., the link volumes of the preceeding intersection that compose a link in the intersection being considered are found. An example is shown in Fig 3.5

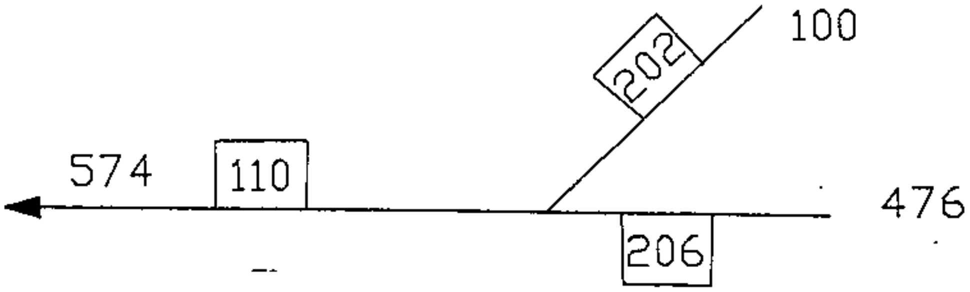

Fig 3.5 Representation of componenets of link volumes

In this example, link 110 is composed of traffic coming from links 202 and 206. Of course, the volume of these links might not add-up to the volume of the link considered, because these links are coming from different phases.

9) All of the previous points are combined together to form a schematic node/link diagram on which every single point of data is represented. This diagram is shown in Fig 3.6. Full details of the required data are presented in Appendix E.

3.4.3) Optimization in TRANSYT-7F:

TRANSYT-7F is used in this research to help in finding the optimal solution that minimizes delay. In order to reach an optimal solution for a particular case, the procedure presented in Table 3.5 is used.

Table 3.5 Recommended procedure for applying TRANSYT-7F

Step	Description	Run
1	Run TRANSYT-7F with the existing timing plan.	Sim.
2	Run TRANSYT-7F with a nominal cycle length number of times to determine the best phase sequence	Opt.
3	Run TRANSYT-7F with the phase sequence detemined to evaluate a range of cycle lengths	Opt.
4	Get the cycle length that gives minimum PI and run the model	Opt.

(Source: TRANSYT-7F, User's Manual, Rel. 6, 1988)

In the following subsections, the method of optimization will be discussed.

A) Input to the Model:

The cycle length selection, which is an important issue

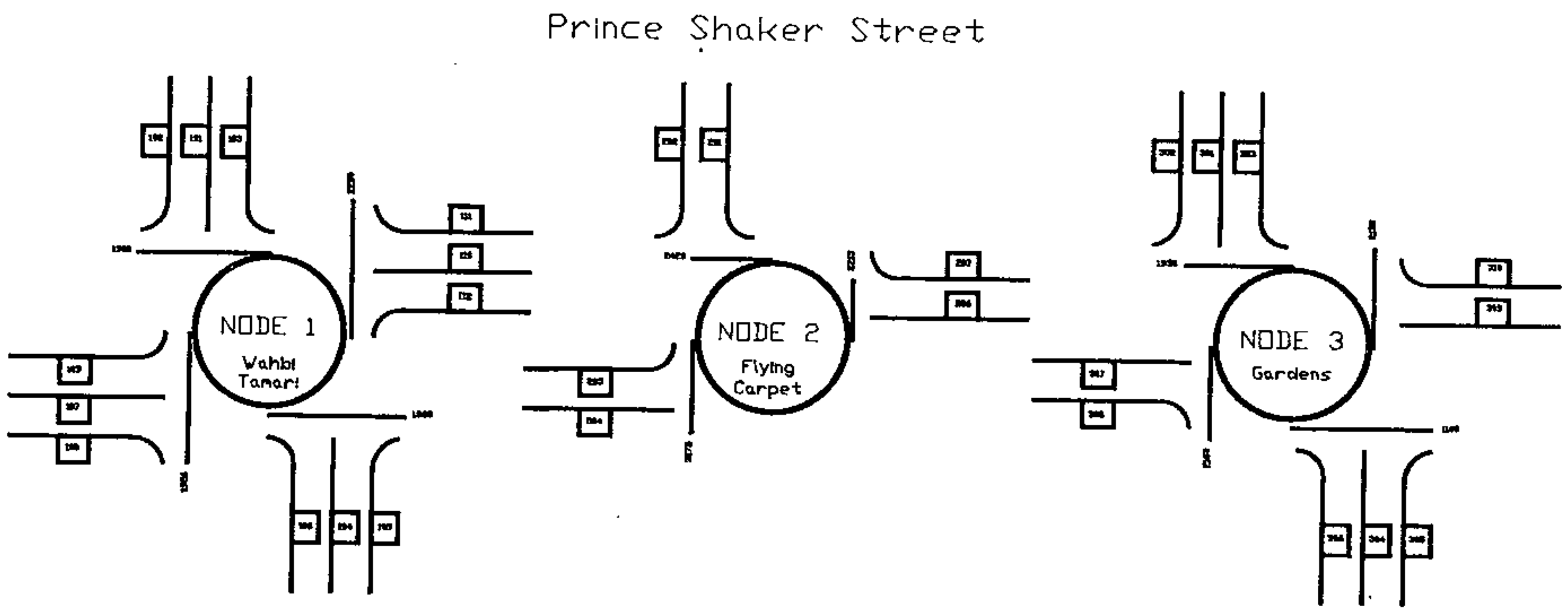

Fig 3.6 Schematic Node/Link Diagram

since it affects delay in the system, can be accomplished automatically in TRANSYT-7F. The user inputs a minimum and a maximum cycle lengths, and a cycle length increment. TRANSYT-7F optimizes phase length for every cycle length between the minimum and the maximum at the input increment. The best cycle length is the one that results in the lowest performance index (P.I.) after phase lengths have been optimized. This process accounts for not only the effects of volume and capacity at individual intersections, but also for the effects of traffic flow patterns in the network and spacing between signals. Other methods such as Webster's formula, only account for volume relationships at individual intersections.

B) Optimization Technique:

The optimization technique used in TRANSYT-7F is based on the gradient search technique(16), which requires extensive numerical computations by the computer. The following steps explain the procedure

Step 1 The initial signal timing plan is simulated by the traffic model, and an initial PI (performance index) is calculated. Simply, the PI is a linear combination of delay and stops.

Step 2 The offset, which is the time difference in seconds between the system time base and the start of a specified interval, is increased. Then Step 1 is repeated.

Step 3 Comparison between the new PI and the previous one is carried out. If the new value of PI is less, then the program continues to increase the offset, otherwise when the PI starts to increase, the program will decrease the offset till PI becomes the minimum. Then the model goes to the next signal in the system. This procedure is shown in Fig 3.7

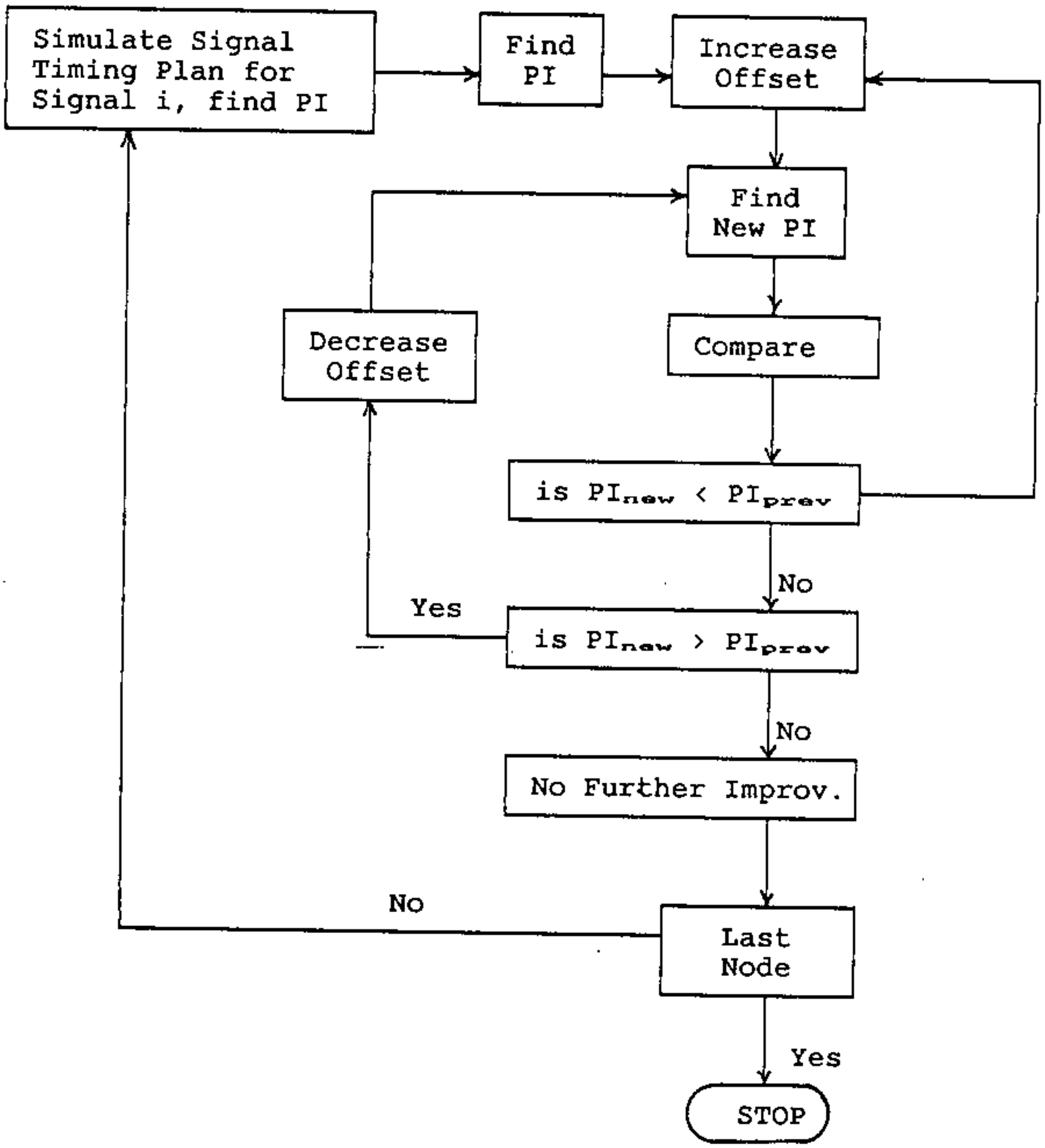

Fig 3.7 Optimization procedure used in TRANSYT-7F

On the other hand, and in order to find the optimal solution (minimum PI) for the system, this could be done by altering the phase sequence along an arterial route. The procedure is shown in Fig 3.8

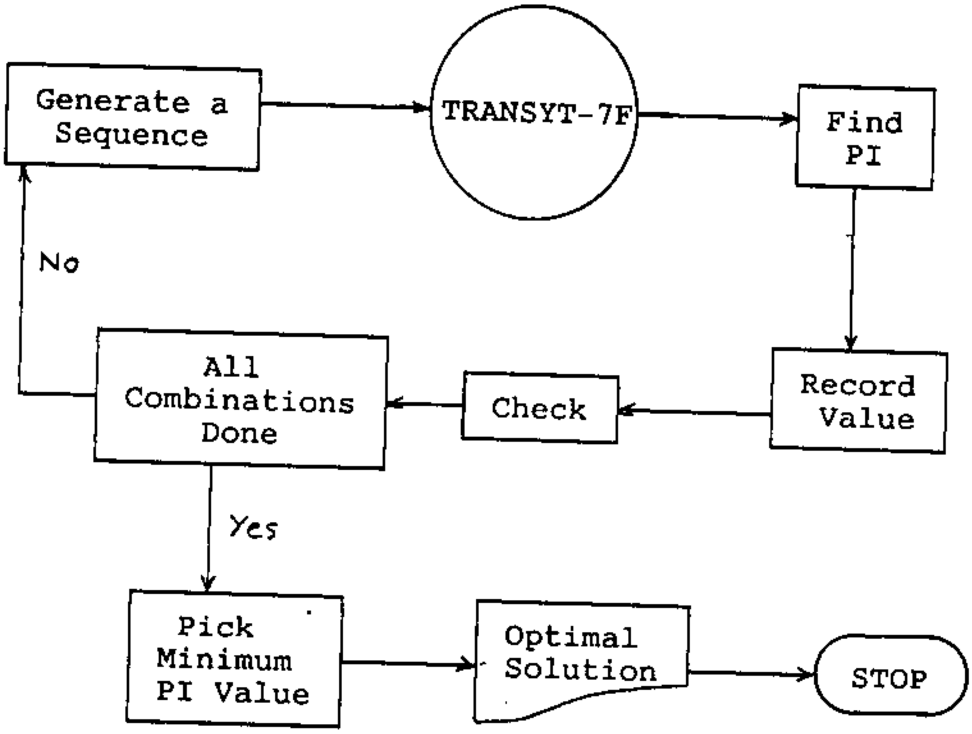

Fig 3.8 Procedure for detemination of system optimal solution

C) Optimization Methodology :

The methododlogy of finding optimal solution is by generating all the possible sequences for all nodes, then running all these combinations in order to find the optimal solution.

In the case of Prince Shaker Street, the possible combinations are 864 cases. This can be illustrated by the following steps :

a) 24 sequences for node 1 (C_4) since there are four approaches

b) 6 sequences for node 2 (C_3)

c) 6 sequences for node 3 (C_3)

d) total combinations = $C_4 * C_3 * C_3$

= (4*3*2)*(3*2)*(3*2) = 864 cases.

In order to run all the combinations (phase sequences) to find the one that results in minimum PI, it will require huge computer time. The Central Processing Unit (CPU) time needed to run one combination, and to make a cycle evaluation over a range of cycle lengths is approximated in Table 3.6

Table 3.6 CPU time (in the average) required to optimize

Processor	PC-XT	PC-AT
Time/Run* (sec)	1726.1	962.5
Time/Run**(sec)	21200	9594.6
Total Time* (hrs)	414.3	231

* Corresponds to One Cycle Length
** Corresponds to Cycle Evaluation Over a Range 90-130 sec

From Table 3.6, it can be shown the amount of time and work needed to find an optimal sequence that develops a minimum performance index. A claim is set in order to minimize the work needed.

Heuristic: **The combination of minimum delay sequence for each node results in the sequence of minimum delay for the system.**

It is difficult to prove this heuristic analytically, however, the procedure claimed in the heuristic is to be tested on a smaller problem to check its correctness. If the procedure works on the problem, one can have higher confidence that it will result in a minimum or near minimum delay for the system.

Test Problem: Choose node 2 and node 3 of Fig 3.6. The possible sequences are 36. By comparing the combination that is claimed previously to other combinations, it was not possible to decrease delay.

When Nodes 2 and 3 of the network are chosen, and all the possible combinations were solved (36 phase sequences), the resulting PI's are shown in Table 3.7

These PI values shown in Table 3.7 are plotted versus the phase sequence in Fig 3.9. The sequence corresponding to minimum PI for each node is selected.

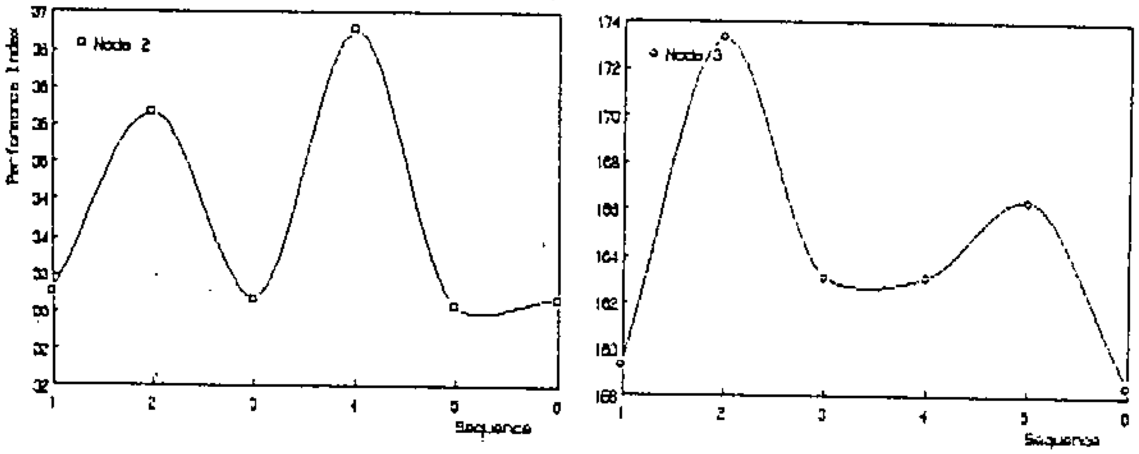

Fig 3.9 PI values plotted against phase sequence

Table 3.7 Resulting PI's for all possible phase sequences of Nodes 2 and 3

	Node				Node		
Phase Sequence	2	3	System Wide	Phase Sequence	2	3	System Wide
1 , 1	33.5	160.1	193.64	4 , 1	37.1	159.6	196.75
1 , 2	33.6	174	207.56	4 , 2	36.8	173.7	210.55
1 , 3	33.9	163.5	197.37	4 , 3	37	164.2	201.28
1 , 4	33.3	169.2	202.49	4 , 4	36.8	163.2	199.99
1 , 5	33.3	167	200.24	4 , 5	36.8	167	203.78
1 , 6	33.7	158.7	192.46	4 , 6	37	159.6	196.6
2 , 1	36	159.9	195.88	5 , 1	33.5	159.4	192.9
2 , 2	35.9	174.8	210.72	5 , 2	33.1	173.4	206.49
2 , 3	36.5	163.2	199.69	5 , 3	33.5	164.2	197.69
2 , 4	40	168.3	208.32	5 , 4	33.3	163.4	196.68
2 , 5	35.7	166.6	202.32	5 , 5	33.4	166.8	200.25
2 , 6	36.4	158.6	194.99	5 , 6	33.4	159.6	192.9
3 , 1	33.5	159.6	193.12	6 , 1	33.5	160.1	193.64
3 , 2	33.2	173.7	206.92	6 , 2	33.2	175.2	208.4
3 , 3	36.1	164.3	200.35	6 , 3	34.4	163.3	197.71
3 , 4	35.7	163.6	199.26	6 , 4	33.3	169.2	202.49
3 , 5	35.8	167	202.78	6 , 5	33.3	166.6	200.12
3 , 6	36.1	159.8	195.89	6 , 6	33.7	159.4	193.13

Another run has been carried out using the timing plan of the selected sequences as shown in Table 3.8. The system wide PI value of this run is compared to values which resulted from all the combinations under study. It was found that this value is the minimum among all other values corresponding to the different combinations. Hence, as expected, the procedure can result in the optimal solution for the system. Consequently, the procedure will be used in solving the case under study in this research.

Table 3.8 PI values for the best sequence combination

	Node		
Sequence	2	3	System Wide
5 , 6	33.4	159.6	192.9

CHAPTER FOUR

Implementation and Results

4.1 Introduction:

The major objectives of signal timing are the minimization of delay and congestion at intersections and within block lengths and series of block lengths between intersections, and the increase in safety for all road users. Full utilization of traffic control signals is realized only when they are operated so as to satisfy, as nearly as possible, actual traffic requirements.

In this chapter, and in order to have a feeling about the difference between solving the problem using the convintional methods such as Webster's, Pignataro's and others, and the other advanced methods using queuing models as TRANSYT-7F, the case of Prince Shaker Street was solved using the two approaches. In the next section, British method has been used to solve the first intersection (Wahbi Tamari) in order to find the signal timing plan.

4.2 Using the Webster's Method to Solve Wahbi Tamari:(1,2,3)

In the case of this intersection, Wahbi Tamari, because the traffic volumes are heavy, and it has four approaches, it requires a longer cycle length than those intersections of lighter traffic volumes and fewer approaches. In general, cycle lengths range from a minimum of 30 sec to a maximum of 120 sec., depending on traffic volumes, approaches, and movements.

In this section, the intersection will be designed using one of the conventional methods, The British Method, in order to have a feeling of how the design will be done. The design is concerned with the morning peak hour from 7:30 to 8:30 a.m.

As mentioned before, this method is mainly concerned with minimizing delay of the intersection. Also, peak-hour-factor (PHF) and saturation flow are the major factors that affect cycle time splitting.

4.2.1 Traffic Flow Data: *

Table 4.1 Traffic flow data for each approach in the a.m. peak hour

TIME	N B		S B		E B		W B		TOTAL
	↳	↲↓	↰	↑↱	↙	←↑	↗	→↓	
7:30 - 7:45	22	78	23	62	40	120	60	235	640
7:45 - 8:00	26	71	28	64	46	116	125	206	682
8:00 - 8:15	22	56	30	68	38	171	84	197	666
8:15 - 8:30	18	47	15	31	7	99	75	211	503
TOTAL	88	252	96	225	131	506	344	849	2491

$$PHF = \frac{\text{Total flow in 1 Hr}}{\text{4 (Max flow of 15 min)}} = \frac{2491}{4*682}$$

$$= 0.913$$

4.2.2 Splitting Effective Green Times:

The effective green times are splitted in proportion of the y_i to Y. A complete computation is found in Appendix D.

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* A complete solution using Webster's Method is found in Appendix D

$y_N = 0.199$ $y_S = 0.189$

$y_E = 0.330$ $y_W = 0.713$ $Y = \sum y_i = 1.431$

Since the summation $y_i > 1$, then set the equation to the maximum cycle length that can be used, $C_o = 120$ seconds.⁽²⁰⁾

$$g_i = \frac{y_i}{Y} (C_o - L)$$

$$g_N = \frac{0.199}{1.431} (120 - 12) = 15.0$$

$$g_S = 0.189 * 75.472 = 14.3$$

$$g_E = 0.330 * 75.472 = 24.9$$

$$g_W = 0.713 * 75.472 = 53.8$$

Then, actual green times, using cycle length C_o=120 seconds, are as follows (Fig 4.1):

g_N = 15 sec.

g_S = 14 sec

g_E = 24 sec

g_W = 51 sec.

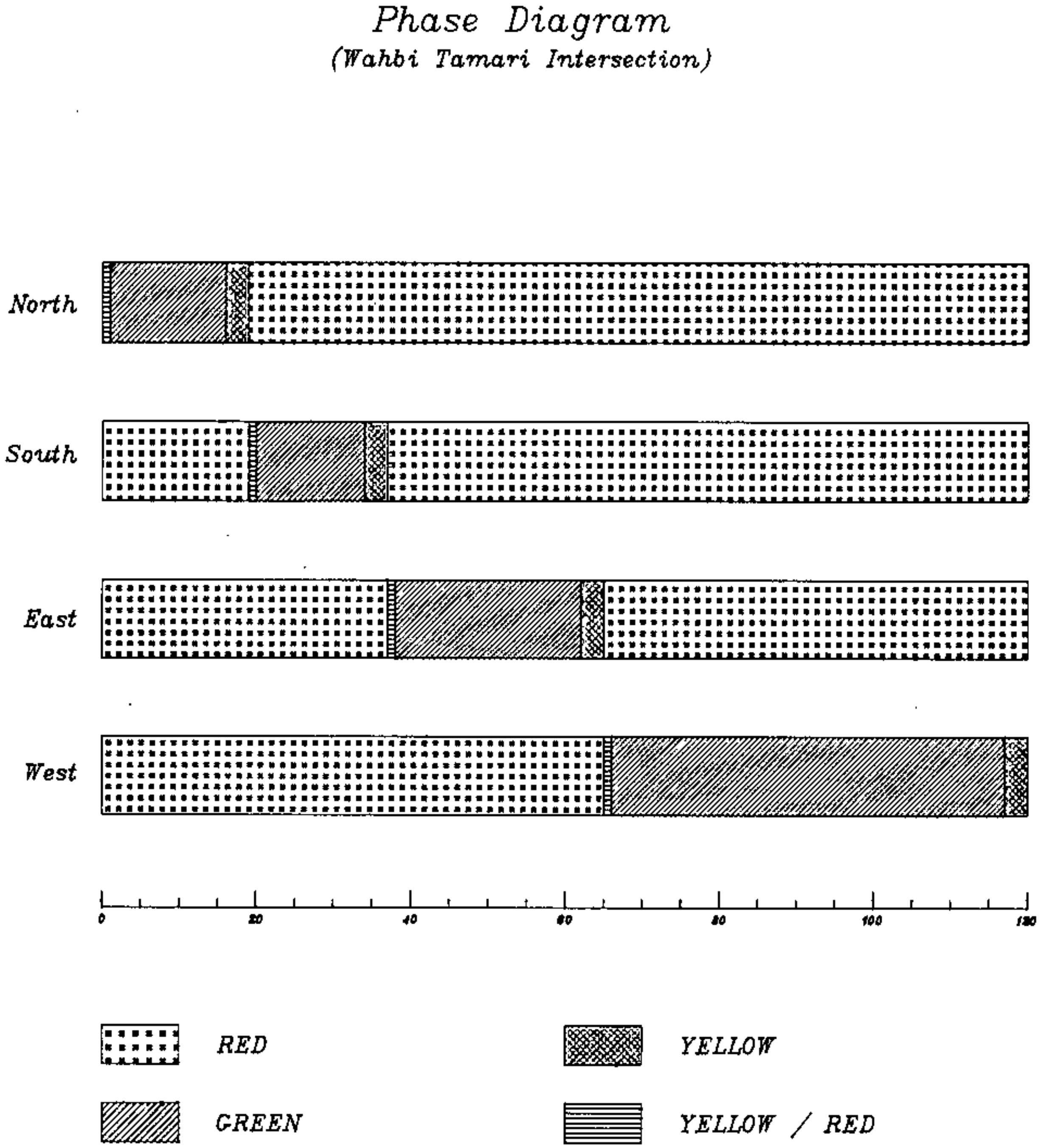


Fig 4.1 Phase diagram of Wahbi Tamari Intersection in the a.m. peak hour

4.3 Analysis Using TRANSYT-7F:

4.3.1) Statistical Analysis of Traffic Data[13,14]

The most important aspect of the simulation of traffic travelling along signalized streets is the manner in which the traffic flow is distributed and modeled. Although TRANSYT models the dispersion of the platoons of vehicles as they progress along a link, determining the distribution of traffic flow in the area of study gives some feeling about the behaviour of traffic in that area. The hypothesis testing technique will be used to test the flow, and what distribution does the traffic data follow. The data used are those of the flow at Wahbi Tamari Intersection as an example. It has four legs, and the traffic data is collected. The data of the south bound leg is shown in the following table:

Table 4.2 Statistical results to test distribution of traffic

TIME PERIOD	INTERVAL (sec)	OBSERVED (Veh/15 min)	EXPECTED (Veh/15 min)	$(O - E)^2$
7:30 - 7:45	900	85	54	961
7:45 - 8:00	900	92	54	1444
8:00 - 8:15	900	98	54	1936
8:15 - 8:30	900	46	54	64
8:30 - 8:45	900	29	54	625
8:45 - 9:00	900	29	54	625
9:00 - 9:15	900	19	54	1225
9:15 - 9:30	900	36	54	324
TOTAL		434		7204

- O means Observed, E means Expected.

In this test, in order to verify if the distribution is Poisson, arrival rate, which is the total traffic in a given time calculated in Veh/Sec., is to be calculated. The other thing to do is to test the "goodness" of fit using the Chi-Square test, according to the following hypothesis:

H_o : Traffic flow follows Poisson distribution

H_1 : Traffic flow does not follow Poisson Dist.

$$q = \frac{434}{2 * 3600} = 0.06 \text{ Veh/Sec.}$$

$$E = q * \text{time interval} = 0.06 * 900 = 54 \text{ veh/15-min}$$

$$X^2_{comp} = \sum \frac{(E - O)^2}{E} = \frac{7204}{434} = 16.676$$

$$X^2_{0.05,6} = 12.592$$

Hence, $X^2_{comp} > X^2_{0.05,6}$

where, q = arrival rate in veh/sec

E = expected flow rate in veh/15-min

O = observed flow rate in veh/15-min

Thus, there is no significant difference between observed and theoritical distribution, so the distribution is considered as **POISSON DISTRIBUTION.**

4.3.2) Calculations of the Case

As presented in Table 3.2, the first step is to run the model using the existing signal timing plan. This plan is shown in Fig 4.2. As it can be seen from the summary of this run, the PI value is 387.70 (Fig 4.3).

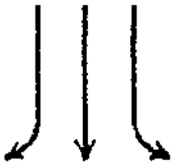
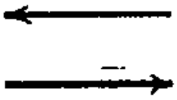
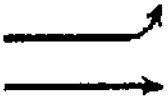
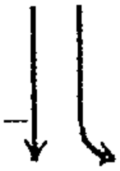
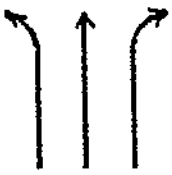
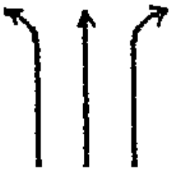
Node 1			Node 2			Node 3		
Phases			Phases			Phases		
Diagram	No	Min	Diagram	No	Min	Diagram	No	Min
	1	17		1	33		1	48
	2	27		2	28		2	28
	3	18		3	39		3	24
	4	38						

Fig 4.2 Installed signal timing plan and phase sequence

```
SIMULATION of Existing (Installed) Phase Sequence and Cycle Length (100 seconds).

<PERFORMANCE WITH INITIAL SETTINGS>               CYCLE:  100 SECONDS,        DATE OF RUN: 12/14/90  START TIME OF RUN:    13:16:54

 NODE LINK   FLOW    SAT   DEGREE  TOTAL       TOTAL    -------- DELAY -------- AVERAGE   UNIFORM    MAX BACK  QUEUE      FUEL  PHASE  LINK
 NO.  NO.           FLOW   OF SAT  TRAVEL      TIME     UNIFORM  RANDOM   TOTAL  DELAY     STOPS     OF QUEUE CAPACITY  CONSUM LENGTH  NO.
            (VEH/H)(VEH/H)  (%)  (VEH-KM/H)(VEH-H/H)          (VEH-H/H)        (SEC/VEH) (VEH/H;%) (VEH/LK)(VEH/LK)  (LI/H) (SEC)

  1   101     10  1900P  104*     2.00       .37      .15      .19      .32  114.2     9.5< 95%>   15         26     1.34   17    101
  1   102    190  1015   104*    38.00      7.12     2.40     3.63     6.03  114.2   181.2< 95%>  101       1015    22.99   17    102
  1   103     96  1015   104*    19.20      3.60     1.21     1.63     3.05  114.2    91.6< 95%>  101       1015    11.61   17    103
  1   104     66  1080P  126*    13.20      4.91      .94     3.59     4.53  247.2    52.2< 79%>   14         26    14.62   18    104
  1   105     50  1045   126*    10.00      3.72      .71     2.72     3.43  247.2    39.6< 79%>  104       1045    11.08   18    105
  1   106    264  1045   126*    52.80     13.64     3.76    14.37    16.13  247.2   209.0< 79%>  104       1045    58.50   18    106
  1   107    844  1950P  164*   337.60    110.49    13.14    82.71   100.84  430.1   514.3< 61%>   63   >    53C   323.22   38    107
  1   108     38  1075   164*    15.20      4.97      .82     3.72     4.54  430.1    23.2< 61%>  107       1075    14.55   38    108
  1   109    270  1075   164*   108.00     35.35     5.80    26.46    32.26  430.1   164.5< 61%>  107       1075   103.40   38    109
  1   110    540  2250P  132*   230.04     50.15    10.51    33.21    43.72  291.5   399.9< 74%>   37         56   151.46   27    110
  1   111     34  1105   132*    14.48      3.15      .64     2.09     2.73  289.3    27.0< 79%>  110       1105     9.50 . 27    111
  1   112    160  1103   132*    71.57     15.60     3.23    10.33    13.56  290.5   135.6< 81%>  110       1105    47.13   27    112

  1 :           2570   MAX = 164*   912.09    259.06    43.29   184.65   232.15  326.6  1047.6< 72%>                    769.40 PI =   176.2

  2   201    850  2420    95*   340.00     20.11     7.07     3.33    10.40   44.0   779.6< 92%>   22         53    75.66   39    201
  2   202    100  1200     8     40.00      1.14      .00      .00      .00     .0      .0<  0%>    0         53     4.50  100    202
  2   204    884  2075    72    376.58     11.60      .64      .46     1.11    4.5   109.5< 12%>    3         56    46.26   61    204
  2   205    376  1100   131*   160.18     29.14     1.31    23.25    24.56  235.2   211.2< 56%>    6         56    88.44   28    205
  2   206    558  2215    81     98.77      9.49     5.94      .85     6.79   43.8   434.4< 78%>   13         23    34.93   33    206
  2   207    256  1200    21     45.31      1.29      .00      .00      .00     .0      .0<  0%>    0         23     5.10  100    207

  2 :           3024   MAX = 131*  1060.84     72.78    14.96    27.89    42.85   51.0  1534.6< 51%>                    254.89 PI =    36.0

  3   301    160  1950P  123*    48.00     11.06     1.92     7.76     9.68  217.9   130.0< 81%>   21         39    33.68   28    301
  3   302    250  1200    21     75.00      2.14      .00      .00      .00     .0      .0<  0%>    0         39     8.44  100    302
  3   303    464  3015   123*   139.20     32.06     5.57    22.52    28.08  217.9   377.0< 81%>  301       3015    97.67   28    303
  3   304    226  1100P  163*   135.60     30.99    |5.09    22.02    27.11  431.9   138.8< 61%>   22         79    91.95   24    304
  3   305    112  3045   163*    67.20     15.36    |2.52    10.91    13.44  431.9    68.8< 61%>  304       3045    45.57   24    305
  3   306     56  3045   163*    33.60      7.68    |1.26     5.46     6.72  431.9    34.4< 61%>  304       3045    22.78   24    306
  3   307   1358  2150P  149*   240.37    129.75    12.39   110.94   123.33  326.9   945.7< 70%>   50   >    23C   380.07   48    307
  3   308    108  3075   149*    19.12     10.37     1.00     8.82     9.83  327.5    43.3< 40%>  307       3075    29.87   48    308
  3   309    854  2150P   96*   256.20     16.93     6.00     3.60     9.61   40.5   769.1< 90%>   26         39    63.92   48    309
  3   310     96  3095    96*    28.80      1.90      .67      .40     1.08   40.5    86.5< 90%>  309       3095     7.19   48    310

  3 :           3684   MAX = 163*  1045.08    258.22    36.43   192.44   228.87  223.7  2593.5< 70%>                    781.13 PI =   175.6

                                                 <SYSTEM WIDE TOTALS INCLUDING ALL LINKS>

   TOTAL        TOTAL     TOTAL      TOTAL       TOTAL     AVERAGE      TOTAL        TOTAL
  DISTANCE     TRAVEL    UNIFORM     RANDOM      DELAY      DELAY      UNIFORM       FUEL     OPERATING PERFORMANCE  SPEED
  TRAVELED      TIME      DELAY      DELAY                              STOPS       CONSUM      COST       INDEX
 (VEH-KM/H)  (VEH-H/H)  (VEH-H/H)  (VEH-H/H)  (VEH-H/H)  (SEC/VEH)   (VEH/H-%)     (LI/H)                          (KM/H)

  3016.01      590.06      99.67     405.20      504.87     195.90    5975.8< 64%>  1805.42     2335.82     387.70      5.11 <TOTALS>
<ROUTE SUMMARY REPORT>    THE TSD ORIENTATION DOWNBOUND ON THE PAGE IS WESTBOUND

 NODE LINK   FLOW    SAT   DEGREE  TOTAL       TOTAL    -------- DELAY -------- AVERAGE   UNIFORM    MAX BACK  QUEUE      FUEL  PHASE  LINK
 NO.  NO.           FLOW   OF SAT  TRAVEL      TIME     UNIFORM  RANDOM   TOTAL  DELAY     STOPS     OF QUEUE CAPACITY  CONSUM LENGTH  NO
            (VEH/H)(VEH/H)  (%)  (VEH-KM/H)(VEH-H/H)          (VEH-H/H)        (SEC/VEH) (VEH/H;%) (VEH/LK)(VEH/LK)  (LI/H) (SEC)

  1   107    844  1950P  164*   337.60    110.49    19.11    82.71   100.84  430.1   514.3< 61%>   63   >    53C   323.22   38    107
  2   204    884  2075    72    376.58     11.60      .64      .46     1.11    4.5   109.5< 12%>    3         56    46.26   61    204
  3   307   1358  2150P  149*   240.37    129.75    12.39   110.94   123.33  326.9   945.7< 70%>   50   >    23C   380.07   48    307

DOWN   :        3086   MAX = 164*   954.55    251.83    31.17   194.11   225.28  262.6  1569.4< 51%>                    749.55 PI =   170.0

  1   110    540  2250P  132*   230.04     50.15    10.51    33.21    43.72  291.5   399.9< 74%>   37         56   151.46   27    110
  2   206    558  2215    81     98.77      9.49     5.94      .85     6.79   43.8   434.4< 78%>   13         23    34.93   33    206
  3   309    854  2150P   96*   256.20     16.93     6.00     3.60     9.61   40.5   769.1< 90%>   26         39    63.92   48    309

UP     :        1352   MAX = 132*   585.01     76.56    22.45    37.66    60.12  110.9  1603.5< 82%>                    250.31 PI =    48.9

                                                 <ROUTE TOTALS>

   TOTAL        TOTAL     TOTAL      TOTAL       TOTAL     AVERAGE      TOTAL        TOTAL
  DISTANCE     TRAVEL    UNIFORM     RANDOM      DELAY      DELAY      UNIFORM       FUEL     OPERATING PERFORMANCE  SPEED
  TRAVELED      TIME      DELAY      DELAY                              STOPS       CONSUM      COST       INDEX
 (VEH-KM/H)  (VEH-H/H)  (VEH-H/H)  (VEH-H/H)  (VEH-H/H)  (SEC/VEH)   (VEH/H-%)     (LI/H)                          (KM/H)

  1539.56      328.40      53.62     231.77      285.39     203.93    3172.9< 63%>   999.86     1260.32     218.62      4.69 <TOTALS>
NOTE: PERFORMANCE INDEX IS DEFINED AS:

      PI = DELAY + STOPS

NO. OF SIMULATIONS =    1  NO. OF LINKS =  28  ELAPSED TIME =    70.5 SEC.
```

Fig 4.3 Simulation of installed signal timing plan

Another run was carried out using the existing signal timing plan and phase sequence, but in the optimization mode. A summary of this run is shown in Fig 4.4. The PI value is 348.83.

It can be seen clearly that changing the phase lengths for the different movements, i.e. the portion of the cycle length given to a certain movement, even by keeping the same phase sequences may result in better performance. Fig 4.5 shows some comparison.

In order to have a feeling about the best cycle length that produces a minimum performance index, while keeping the same phase sequence, an optimization run has been done over a range of cycle lengths from 90-130 seconds. It has been determined that by using the existing phase sequences for the three intersections we deal with, the best cycle length was found

to be 125 seconds, which gives a PI value of 341.07. This result is shown in Fig 4.6.

In order to reach a good solution (optimal or near-optimal), an algorithm has been developed. In the next section, the algorithm and its implementation are presented.

```
SEQUENCE 1.1.1


DATE OF RUN: 11/16/90   START TIME OF RUN:    3:46:20


<PERFORMANCE WITH OPTIMAL SETTINGS>                          CYCLE:  100 SECONDS,

 NODE LINK   FLOW    SAT   DEGREE  TOTAL      TOTAL   --------- DELAY ---------  AVERAGE   UNIFORM    MAX BACK  QUEUE     FUEL  PHASE  LINK
  NO.  NO.          FLOW   OF SAT  TRAVEL     TIME    UNIFORM  RANDOM   TOTAL    DELAY     STOPS     OF QUEUE CAPACITY CONSUM LENGTH  NO.
            (VEH/H)(VEH/H)  (%)  (VEH-KM/H)(VEH-H/H)        (VEH-H/H)           (SEC/VEH) (VEH/H;%)  (VEH/LK)(VEH/LK)   (LI/H)  (SEC)

  1   101     10  1900P   120M      2.00       .65      .14      .45      .53  213.0     8.5( 83%)   11        25     2.09    15    101
  1   102    190   1015   120M     38.00     12.33     2.67     8.58    11.24  213.0   158.5( 83%)  101      1015    37.19    15    102
  1   103     96   1015   120M     19.20      6.23     1.35     4.33     5.68  213.0    80.1( 83%)  101      1015    18.73    15    103
  1   104     66  1080P   144M     13.20      6.09     1.34     5.17     6.51  355.1    45.7( 69%)   20        25    20.04    16    104
  1   105     50   1045   144M     10.00      5.22     1.02     3.31     4.93  355.1    34.5( 69%)  104      1045    15.10    16    105
  1   106    264   1045   144M     52.80     27.55     5.38    20.66    26.04  355.1   182.9( 69%)  104      1045    80.15    16    106
  1   107    844  1950P   164M    337.60    106.37    14.02    82.71    96.72  412.6   514.3( 61%)   49        53   311.79    38    107
  1   108     38   1075   164M     15.20      4.73      .63     3.72     4.35  412.6    23.2( 61%)  107      1075    14.04    38    108
  1   109    270   1075   164M    108.00     34.03     4.48    26.46    30.94  412.6   164.5( 61%)  107      1075    99.74    38    109
  1   110    540  2250P   114M    230.04     28.73     4.72    17.49    22.21  148.1   448.7( 83%)   23        56    92.41    31    110
  1   111     34   1105   114M     14.40      1.80      .28     1.10     1.39  146.7    27.0( 79%)  110      1105     5.77    31    111
  1   112    168   1105   114M     71.57      9.92     1.43     5.44     6.87  147.3   136.1( 81%)  110      1105    29.61    31    112

  1 :          2570    MAX = 164M    312.09    243.56    37.46   180.03   217.50  304.7  1824.0( 71%)                  725.80 PI =  164.6

  2   201    850   2420   100M    340.00     24.82     7.67     7.43    15.10   64.0   809.6( 95%)   41        53    83.03    37    201
  2   202    100   1200     8      40.00      1.14      .00      .00      .00     .0      .0(  0%)    0        53     4.50   100    202
  2   204    884   2075    70     376.58     12.49     1.33      .40     1.73    7.0   172.1( 19%)    5        56    49.06    63    204
  2   205    376   1100   107M    160.18     13.96      .92     8.46     9.38   89.8   113.8( 30%)    4        56    45.29    34    205
  2   206    558   2215    93      98.77      8.84     3.51     2.51     6.02   38.8   489.2( 88%)   14        23    33.18    29    206
  2   207    256   1200    21      45.31      1.29      .00      .00      .00     .0      .0(  0%)    0        23     5.10   100    207

  2 :          3024    MAX = 107M   1060.84     62.54    13.43    18.80    32.23   38.4  1594.8( 52%)                  226.16 PI =   28.2

  3   301    160  1950P   160M     48.00     13.13     2.65    15.11    17.76  399.6   100.0( 62%)   35        39    55.73    22    301
  3   302    250   1200    21      75.00      2.14      .00      .00      .00     .0      .0(  0%)    0        39     8.44   100    302
  3   303    464   3015   160M    139.20     55.40     7.69    43.81    51.50  399.6   290.0( 62%)  301      3015   161.62    22    303
  3   304    226  1100P   199M    135.60     37.65     5.53    28.25    33.79  539.1   113.6( 50%)   22        79   110.16    20    304
  3   305    112   3045   199M     67.20     10.66     2.74    14.00    16.74  539.1    56.3( 50%)  304      3045    54.59    20    305
  3   306     56   3045   199M     33.60      9.33     1.37     7.00     8.37  539.1    28.1( 50%)  304      3045    27.30    20    306
  3   307   1358  2150P   122M    240.37     73.13     4.55    61.71    66.26  175.7   677.4( 50%)   28   >   230   219.21    58    307
  3   308    108   3075   122M     19.12      5.91      .46     4.91     5.37  178.8    66.6( 62%)  307      3075    17.76    58    308
  3   309    854  2150P    79     256.20     12.02     4.05      .65     4.70   19.8   624.0( 73%)   20        39    48.73    58    309
  3   310     96   3095    79      28.80      1.55      .46      .07      .53   19.8    70.1( 73%)  309      3035     5.48    58    310

  3 :          3684    MAX = 199M   1043.08    234.81    29.50   175.51   205.01  200.3  2026.1( 55%)                  708.01 PI =  156.0


                                    <SYSTEM WIDE TOTALS INCLUDING ALL LINKS>

   TOTAL       TOTAL     TOTAL      TOTAL      TOTAL    AVERAGE      TOTAL        TOTAL
  DISTANCE     TRAVEL   UNIFORM     RANDOM     DELAY     DELAY      UNIFORM        FUEL    OPERATING PERFORMANCE  SPEED
  TRAVELED     TIME      DELAY      DELAY                            STOPS        CONSUM     COST       INDEX
 (VEH-KM/H) (VEH-H/H) (VEH-H/H)  (VEH-H/H)  (VEH-H/H)  (SEC/VEH)   (VEH/H-%)      (LI/H)                          (KM/H)

  2016.01     540.90     80.40     374.33     454.73     176.44   5434.9( 59%)   1653.97    2152.56     348.83        5.58 <TOTALS>


NOTE: PERFORMANCE INDEX IS DEFINED AS:

      PI = DELAY + STOPS

NO. OF SIMULATIONS =  21  NO. OF LINKS = 318  ELAPSED TIME =  1908.8 SEC.
```

Fig 4.4 Optimization of installed signal timing plan and phase sequence

```
*** Comparison between the performance with INITIAL and OPTIMUM settings for the installed phase sequence and signal timing plan.

 DATE OF RUN: 12/14/90  START TIME OF RUN:    13:16:54

<PERFORMANCE WITH INITIAL SETTINGS>          CYCLE:  100 SECONDS      <PERFORMANCE WITH OPTIMAL SETTINGS>          CYCLE:  100 SECONDS.

NODE LINK     TOTAL   AVERAGE     UNIFORM      FUEL  PHASE  LINK      NODE LINK     TOTAL   AVERAGE     UNIFORM      FUEL  PHASE  LINK
 NO.  NO.      TIME     DELAY       STOPS    CONSUM LENGTH   NO.       NO.  NO.      TIME     DELAY       STOPS    CONSUM LENGTH   NO.
          <VEH-H/H> <SEC/VEH>   <VEH/H;%>    <LI/H>  <SEC>                      <VEH-H/H> <SEC/VEH>   <VEH/H;%>    <LI/H>  <SEC>

  1   101      .37     114.2     9.5( 95%)     1.34    17   101         1   101      .65     213.0     8.3( 83%)     2.09    15   101
  1   102     7.12     114.2   181.2( 95%)    22.99    17   102         1   102    12.33     213.0   158.5( 83%)    37.19    15   102
  1   103     3.60     114.2    91.6( 95%)    11.61    17   103         1   103     6.23     213.0    80.1( 83%)    18.79    15   103
  1   104     4.91     247.2    52.2( 79%)    14.62    18   104         1   104     6.09     355.1    45.7( 69%)    20.04    16   104
  1   105     3.72     247.2    39.6( 79%)    11.08    18   105         1   105     5.22     355.1    34.6( 69%)    15.18    16   105
  1   106    19.64     247.2   209.0( 79%)    58.50    18   106         1   106    27.55     355.1   182.9( 69%)    80.15    16   106
  1   107   110.49     430.1   514.3( 61%)   323.22    38   107         1   107   106.37     412.6   514.3( 61%)   311.79    38   107
  1   108     4.97     430.1    23.2( 61%)    14.55    38   108         1   108     4.79     412.6    23.2( 61%)    14.04    38   108
  1   109    35.35     430.1   164.5( 61%)   103.40    38   109         1   109    34.03     412.6   164.5( 61%)    99.74    38   109
  1   110    50.15     291.5   399.9( 74%)   151.46    27   110         1   110    28.79     148.1   448.7( 83%)    92.41    31   110
  1   111     3.15     289.3    27.0( 79%)     9.50    27   111         1   111     1.80     146.7    27.0( 79%)     5.77    31   111
  1   112    15.60     290.5   135.6( 81%)    47.13    27   112         1   112     8.92     147.3   136.1( 81%)    28.61    31   112

  1 :       259.06     326.6  1847.6( 72%)   769.40 PI =  176.2         1 :       243.56     304.7  1824.0( 71%)   725.80 PI =  164.6

  2   201    20.11      44.0   779.6( 92%)    75.66    39   201         2   201    24.82      64.0   809.6( 95%)    89.03    37   201
  2   202     1.14        .0      .0(  0%)     4.50   100   202         2   202     1.14        .0      .0(  0%)     4.50   100   202
  2   204    11.60       4.5   109.5( 12%)    46.26    61   204         2   204    12.49       7.0   172.1( 19%)    49.06    63   204
  2   205    29.14     235.2   211.2( 56%)    88.44    28   205         2   205    13.96      89.8   113.8( 30%)    45.29    34   205
  2   206     9.49      43.8   434.4( 78%)    34.93    33   206         2   206     8.84      38.8   489.2( 88%)    33.18    29   206
  2   207     1.29        .0      .0(  0%)     5.10   100   207         2   207     1.29        .0      .0(  0%)     5.10   100   207

  2 :        72.78      51.0  1534.6( 51%)   254.89 PI =   36.0         2 :        62.54      38.4  1584.8( 52%)   226.16 PI =   28.2

  3   301    11.06     217.9   130.0( 81%)    33.68    28   301         3   301    19.13     393.6   100.0( 62%)    55.73    22   301
  3   302     2.14        .0      .0(  0%)     8.44   100   302         3   302     2.14        .0      .0(  0%)     8.44   100   302
  3   303    32.06     217.9   377.0( 81%)    97.67    28   303         3   303    55.48     393.6   290.0( 62%)   161.62    22   303
  3   304    30.99     431.9   138.8( 61%)    91.35    24   304         3   304    37.65     538.1   113.6( 50%)   110.16    20   304
  3   305    15.56     431.9    68.8( 61%)    45.57    24   305         3   305    18.66     538.1    56.3( 50%)    54.59    20   305
  3   306     7.68     431.9    34.4( 61%)    22.78    24   306         3   306     9.33     538.1    28.1( 50%)    27.30    20   306
  3   307   129.75     326.9   945.7( 70%)   380.07    48   307         3   307    73.13     175.7   677.4( 50%)   218.21    58   307
  3   308    10.37     327.5    43.3( 40%)    29.87    48   308         3   308     5.91     178.8    66.6( 62%)    17.76    58   308
  3   309    16.93      40.5   769.1( 90%)    63.92    48   309         3   309    12.02      19.8   624.0( 73%)    48.73    58   309
  3   310     1.90      40.5    86.5( 90%)     7.19    48   310         3   310     1.35      19.8    70.1( 73%)     5.48    58   310

  3 :       258.22     223.7  2593.5( 70%)   781.13 PI =  175.6         3 :       234.81     200.3  2026.1( 55%)   708.01 PI =  156.0


                                              <SYSTEM WIDE TOTALS INCLUDING ALL LINKS>

  <PERFORMANCE WITH INITIAL SETTINGS>
   TOTAL       TOTAL      TOTAL      TOTAL      TOTAL    AVERAGE       TOTAL        TOTAL
  DISTANCE     TRAVEL     UNIFORM    RANDOM     DELAY     DELAY       UNIFORM        FUEL   OPERATING PERFORMANCE  SPEED
  TRAVELED      TIME      DELAY      DELAY                             STOPS        CONSUM     COST      INDEX
 <VEH-KM/H>  <VEH-H/H>  <VEH-H/H>  <VEH-H/H>  <VEH-H/H>  <SEC/VEH>   <VEH/H-%>      <LI/H>                         <KM/H>

  3016.01     590.06      33.67     405.20     504.07     195.90   5975.8( 64%)   1805.42    2335.82    387.70       5.11 <TOTALS>
NOTE: PERFORMANCE INDEX IS DEFINED AS:

      PI = DELAY + STOPS

NO. OF SIMULATIONS =    1  NO. OF LINKS =  28  ELAPSED TIME =     51.4 SEC.


  <PERFORMANCE WITH OPTIMAL SETTINGS>
   TOTAL       TOTAL      TOTAL      TOTAL      TOTAL    AVERAGE       TOTAL        TOTAL
  DISTANCE     TRAVEL     UNIFORM    RANDOM     DELAY     DELAY       UNIFORM        FUEL   OPERATING PERFORMANCE  SPEED
  TRAVELED      TIME      DELAY      DELAY                             STOPS        CONSUM     COST      INDEX
 <VEH-KM/H>  <VEH-H/H>  <VEH-H/H>  <VEH-H/H>  <VEH-H/H>  <SEC/VEH>   <VEH/H-%>      <LI/H>                         <KM/H>.

  3016.01     540.90      80.40     374.33     454.73     176.44   5434.9( 59%)   1659.97    2152.56    348.83       5.58 <TOTALS>

NOTE: PERFORMANCE INDEX IS DEFINED AS:

      PI = DELAY + STOPS

NO. OF SIMULATIONS =  21  NO. OF LINKS = 318  ELAPSED TIME =  1908.8 SEC.
```

Fig 4.5 Comparison between initial and optimal setting of installed phase sequence

```
SEQUENCE 1,1,1: Existing (Installed) Phase Sequence and Signal Timing Plan
                                                                    DATE OF RUN: 12/ 7/90   START TIME OF RUN:    16:10:14
                 CYCLE EVALUATION SUMMARY PERFORMANCE
                 ------------------------------------
 CYCLE   STEP   AVERAGE  PERCENT      FUEL      PERFORMANCE  NUMBER
LENGTH   SIZE    DELAY    STOPS    CONSUMPTION    INDEX     SATURATED
 (SEC) (STEPS) (SEC/VEH)   (%)       (GAL/HR)                 LINKS
----------------------------------------------------------------------
  110     37    173.86     57        1640.0       344.0        21
  115     38    173.89     55        1637.0       343.4        22
  120     40    172.75     59        1634.1       342.4        22
  125     42    172.30     56        1632.4       342.0        22
  130     43    173.38     56        1635.4       342.8        22
----------------------------------------------------------------------
     BEST CYCLE LENGTH = 125 SEC.    CYCLE SENSITIVITY =     .2 %

<PERFORMANCE WITH OPTIMAL SETTINGS>                              CYCLE:   125 SECONDS,

  NODE LINK    FLOW    SAT   DEGREE  TOTAL       TOTAL   --------- DELAY --------- AVERAGE    UNIFORM    MAX BACK  QUEUE     FUEL  PHASE  LINK
  NO.  NO.             FLOW  OF SAT  TRAVEL      TIME    UNIFORM  RANDOM   TOTAL   DELAY      STOPS      OF QUEUE CAPACITY  CONSUM LENGTH  NO.
              (VEH/H)(VEH/H)  (%)  (VEH-KM/H)(VEH-H/H)        (VEH-H/H)          (SEC/VEH) (VEH/H;%)  (VEH/LK)(VEH/LK)   (LI/H)  (SEC)

   1   101      10  1900P  133*     2.00       .98       .20     .72      .92   332.1      7.2( 72%)    15         26      2.99    16    101
   1   102     190   1015  133*    38.00     18.61      3.79   13.74    17.53   332.1    136.6( 72%)   101       1015     54.37    16    102
   1   103      96   1015  133*    19.20      9.40      1.91    6.94     8.86   332.1     69.0( 72%)   101       1015     27.47    16    103
   1   104      66  1880P  169*    13.20      9.13      1.99    6.77     8.75   477.4     39.2( 59%)    25         26     26.10    17    104
   1   105      50   1045  168*    10.00      6.92      1.50    5.13     6.63   477.4     29.7( 59%)   104       1045     19.83    17    105
   1   106     264   1045  168*    52.80     36.52      7.95   27.07    35.01   477.4    156.7( 59%)   104       1045    104.73    17    106
   1   107     844  1950P  142*   337.60     87.66     15.16   62.85    78.01   332.7    594.3( 70%)    62    >   530    260.80    54    107
   1   108      38   1075  142*    15.20      3.95       .66    2.83     3.51   332.7     26.8( 70%)   107       1075     11.74    54    108
   1   109     270   1075  142*   108.00     28.04      4.85   20.11    24.96   332.7    190.1( 70%)   107       1075     83.43    54    109
   1   110     540  2250P  115*   230.04     29.02      4.34   10.25    22.60   150.6    457.1( 85%)    29         56     93.54    38    110
   1   111      34   1105  115*    14.49      1.01       .24    1.15     1.39   147.5     27.7( 81%)   110       1105      5.80    38    111
   1   112     160   1105  115*    71.57      8.95      1.23    5.68     6.91   140.0    139.3( 83%)   110       1105     28.73    38    112

   1 :          2570   MAX = 160*   912.03    240.99     45.04  171.24   215.08   301.3   1073.6( 73%)                       719.62 PI =  163.0

   2   201     850   2420   95*   340.00     22.07      8.78    3.57    12.35    52.3    785.0( 92%)    20         53     81.15    48    201
   2   202     100   1200    8     40.00      1.14       .00     .00      .00      .0       .0(  0%)     0         53      4.50   125    202
   2   204     894   2075   71    376.58     11.66       .93    -.43     1.36     5.5    105.5( 12%)     4         56     46.92    77    204
   2   205     376   1100  104*   160.18     12.56      1.12    6.87     7.99    76.5    188.4( 50%)     7         56     42.24    43    205
   2   206     558   2215   98*    98.77     12.52      5.17    4.64     9.82    63.3    517.3( 93%)    18         23     44.32    34    206
   2   207     256   1200   21     45.31      1.29       .00     .00      .00      .0       .0(  0%)     0         23      5.10   125    207

   2 :          3024   MAX = 104*  1060.04     61.45     16.01   15.51    31.52    37.5   1596.2( 53%)                       224.24 PI =   27.9

   3   301     160  1950P  154*    48.00     18.66      3.17   14.12    17.28   388.9    104.0( 65%)    30         39     54.46    28    301
   3   302     250   1200   21     75.00      2.14       .00     .00      .00      .0       .0(  0%)     0         39      8.44   125    302
   3   303     464   3015  154*   139.20     54.10      9.19   40.94    50.13   388.9    301.6( 65%)   301       3015    157.95    28    303
   3   304     226  1100P  236*   135.60     43.93      7.43   32.63    40.05   638.0     95.9( 42%)    27         79    127.36    21    304
   3   305     112   3045  236*    67.20     21.77      3.68   16.17    19.85   638.0     47.5( 42%)   304       3045     63.11    21    305
   3   306      56   3045  236*    33.60     10.80      1.84    8.09     9.92   638.0     23.8( 42%)   304       3045     31.56    21    306
   3   307    1358  2150P  115*   240.37     56.60      3.98   46.20    50.19   133.0    635.0( 47%)    34    >   230    173.39    76    307
   3   308     108   3075  115*    19.12      4.71       .49    3.67     4.16   138.8     71.7( 66%)   307       3075     14.49    76    308
   3   309     854  2150P   75    256.20     12.19      4.38     .49     4.87    20.5    586.8( 69%)    24         39     48.79    76    309
   3   310      96   3095   75     28.80      1.37       .49     .05      .55    20.5     66.0( 69%)   309       3095      5.48    76    310

   3 :          3684   MAX = 236*  1043.09    226.36     34.65  162.36   197.01   192.5   1932.3( 52%)                       685.03 PI =  150.2

                                           <SYSTEM WIDE TOTALS (INCLUDING ALL LINKS)>

   TOTAL        TOTAL      TOTAL      TOTAL      TOTAL     AVERAGE       TOTAL        TOTAL
  DISTANCE      TRAVEL    UNIFORM     RANDOM     DELAY      DELAY       UNIFORM        FUEL    OPERATING PERFORMANCE  SPEED
  TRAVELED      TIME       DELAY      DELAY                              STOPS        CONSUM      COST       INDEX
 (VEH-KM/H)  (VEH-H/H)  (VEH-H/H)  (VEH-H/H)  (VEH-H/H)  (SEC/VEH)    (VEH/H-%)      (LI/H)                          (KM/H)

  3016.01      528.80      94.50     349.11     443.61     172.13    5402.1( 58%)  1628.89     2115.61     341.07      5.70 <TOTALS>

<ROUTE SUMMARY REPORT>     THE 1ST ORIENTATION DOWNBOUND ON THE PAGE IS WESTBOUND

  NODE LINK    FLOW    SAT   DEGREE  TOTAL       TOTAL   --------- DELAY --------- AVERAGE    UNIFORM    MAX BACK  QUEUE     FUEL  PHASE  LINK
  NO.  NO.             FLOW  OF SAT  TRAVEL      TIME    UNIFORM  RANDOM   TOTAL   DELAY      STOPS      OF QUEUE CAPACITY  CONSUM LENGTH  NO
              (VEH/H)(VEH/H)  (%)  (VEH-KM/H)(VEH-H/H)        (VEH-H/H)          (SEC/VEH) (VEH/H;%)  (VEH/LK)(VEH/LK)   (LI/H)  (SEC)

   1   107     844  1950P  142*   337.60     37.66     15.16   62.85    78.01   332.7    594.3( 70%)    62    >   530    260.80    54    107
   2   204     894  2075    71    376.58     11.06       .93    -.43     1.36     5.5    105.5( 12%)     4         56     46.92    77    204
   3   307    1358  2150P  115*   240.37     56.60      3.98   46.20    50.19   133.0    635.0( 47%)    34    >   230    173.39    76    307

DOWN   :        3096   MAX = 142*   954.55    156.12     20.07  109.49   129.56   151.1   1334.0( 45%)                       481.11 PI =   99.0

   1   110     540  2250P  115*   230.04     29.02      4.34   18.25    22.60   150.6    457.1( 85%)    28         56     93.54    38    110
   2   206     558  2215    98*    98.77     12.52      5.17    4.64     9.82    63.3    517.3( 93%)    18         23     44.32    34    206
   3   309     854  2150P   75    256.20     12.19      4.38     .49     4.87    20.5    586.8( 69%)    24         39     48.79    76    309

UP     :        1952   MAX = 115*   505.01     53.73     13.90   23.39    37.28    68.8   1561.2( 80%)                       186.66 PI =   32.0

                                                  <ROUTE TOTALS>

   TOTAL        TOTAL      TOTAL      TOTAL      TOTAL     AVERAGE       TOTAL        TOTAL
  DISTANCE      TRAVEL    UNIFORM     RANDOM     DELAY      DELAY       UNIFORM        FUEL    OPERATING PERFORMANCE  SPEED
  TRAVELED      TIME       DELAY      DELAY                              STOPS        CONSUM      COST       INDEX
 (VEH-KM/H)  (VEH-H/H)  (VEH-H/H)  (VEH-H/H)  (VEH-H/H)  (SEC/VEH)    (VEH/H-%)      (LI/H)                          (KM/H)

  1539.56      203.85      33.97     132.87     166.84     119.22    2896.0( 57%)   667.77      854.07     131.09      7.34 <TOTALS>
```

Fig 4.6 , Optimization over a range of cycle lengths assuming installed phase sequence

4.4 Developed Algorithm:

There are three parameters that affect the solution in TRANSYT. These are cycle length C, sequence S, and timing plan T. The logical way that leads to a good solution is presented in Fig4.7. Using the Hierarchical Decomposition will lead to understand better how to reach the solution.

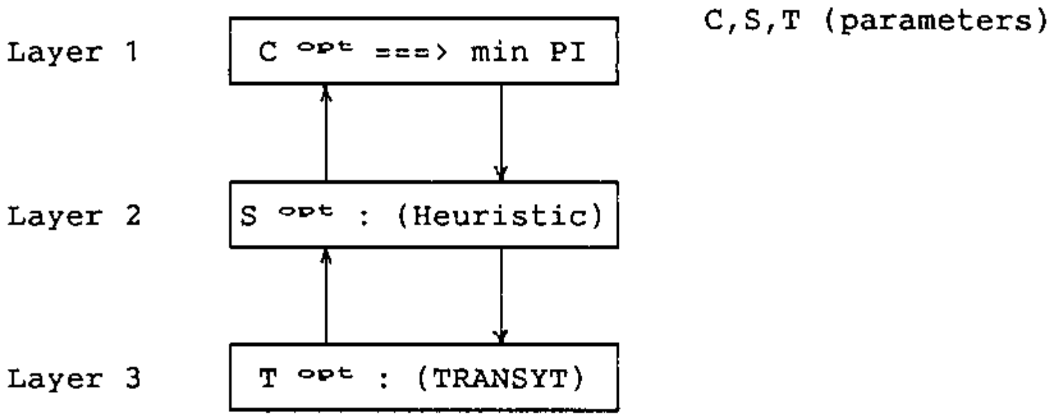


Fig 4.7 Hierarchical decomposition

The procedure of each layer is described below.

Layer 1: the user starts by inserting a nominal cycle length, and preferably, the installed one.

Layer 2: using the Heuristic described before (p. 41), we find the best sequence for each node.

Layer 3: then, the sequence found in layer 2 is used to find the best timing plan and cycle length for that specific sequence.

The iterations continue between Layer 2 and Layer 3 (regenerate new sequence using the resulting cycle length by applying Heuristic) until we reach a steady-state. This means that, the resulting sequence and timing plan and cycle length are optimal or near-optimal. The resulting cycle length from Layers 2 and 3 is the best that can be obtained.

Taking into consideration the way that the decomposition works, the new algorithm has been developed. The procedure for this algorithm is shown in Fig 4.8. Also, the flow chart of the procedure is shown in Fig 4.9.

STEP 1

Find sequence for each node such that:

$PI_{min} = min_l \; min_k \; min_m \; (PI)_{lkm}$

STEP 2

Find optimal cycle length for system with combination of sequence found in STEP 1.

STEP 3

If cycle length is the same as used in STEP 1, **STOP**.

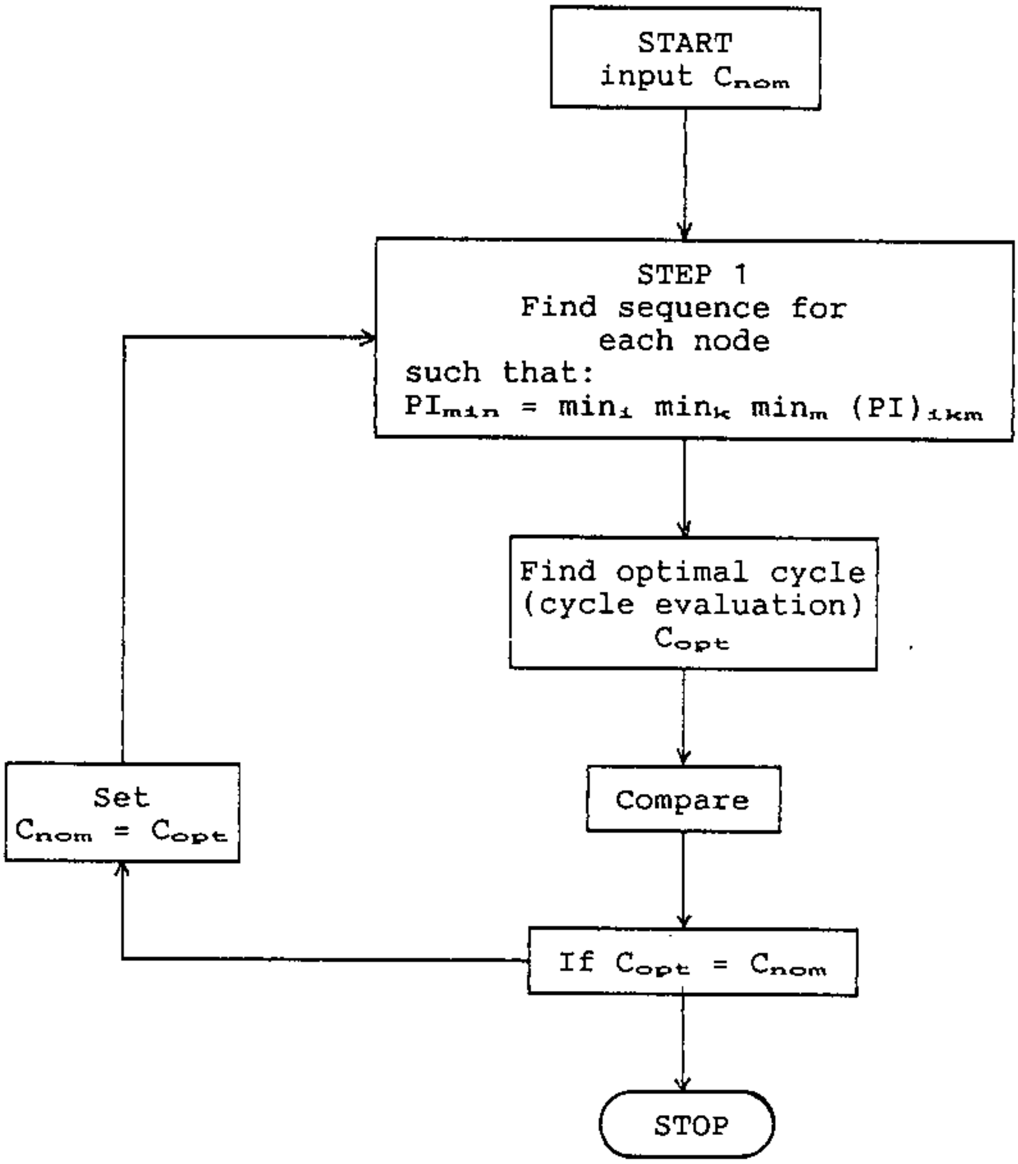
Otherwise, Go to STEP 4.

STEP 4

Repeat STEP 1 with cycle length found in STEP 2.

GO TO STEP 2.

Fig 4.8 Algorithm to find an optimal or near optimal solution



<u>Fig 4.9</u> Flow chart presenting the procedure of algorithm

4.4.1) Implementation of Algorithm:

The algorithm shown in Fig 4.8 has been implemented. TRANSYT has been run with several iterations as it can be seen in the following pages. These iterations cover all the possible phase sequences for each node. In other words, 24 sequences for node 1, 6 sequences for node 2, and 6 sequences for node 3.

ITERATION : 1

Input Cycle Length: 100 seconds

Resulting Sequence: 19,5,1

Resulting PI Value: 346.93

Best Cycle Length Over Range: 120 seconds

Resulting PI Value: 349.14

Reference: Table 4.3, Fig 4.10, Fig 4.11

Table 4.3 Resulting PI's for cycle length of 100 sec.

Phase Sequence	Node			System Wide
	1	2	3	
1,1,1	165	28.2	155.5	348.65
2,2,2	163.9	29.8	166.7	360.38
3,3,3	164.3	30.4	153.2	347.97
4,4,4	163.5	31.1	161.5	356.16
5,5,5	167.4	27.3	157.3	352.02
6,6,6	164.5	28.7	158.1	351.21
7,6,1	166.1	30	154	350.03
8,1,2	165.3	28.6	168.5	362.38
9,2,3	166.2	30.1	151.7	348.05
10,3,4	163.3	30.6	161.7	355.6
11,4,5	164.2	31.1	159.9	355.23
12,5,6	164.8	28.9	154.7	348.43
13,6,1	167.5	28.6	151.4	347.55
14,5,2	163.3	29.3	166.6	349.25
15,4,3	166.1	30.9	153.9	350.91
16,3,4	164.5	30.5	163.5	358.52
17,2,5	167.3	29.8	159.3	356.44
18,6,1	164.7	28.2	151.4	344.24
19,5,2	162.8	30.4	166.7	359.95
20,1,6	164.4	29.4	152.7	346.53
21,2,1	164.3	30.4	152.9	347.65
22,3,2	164.1	31.3	166.6	361.97
23,4,3	165.8	32.3	154.2	352.31
24,5,4	164.6	28.4	161.4	354.37

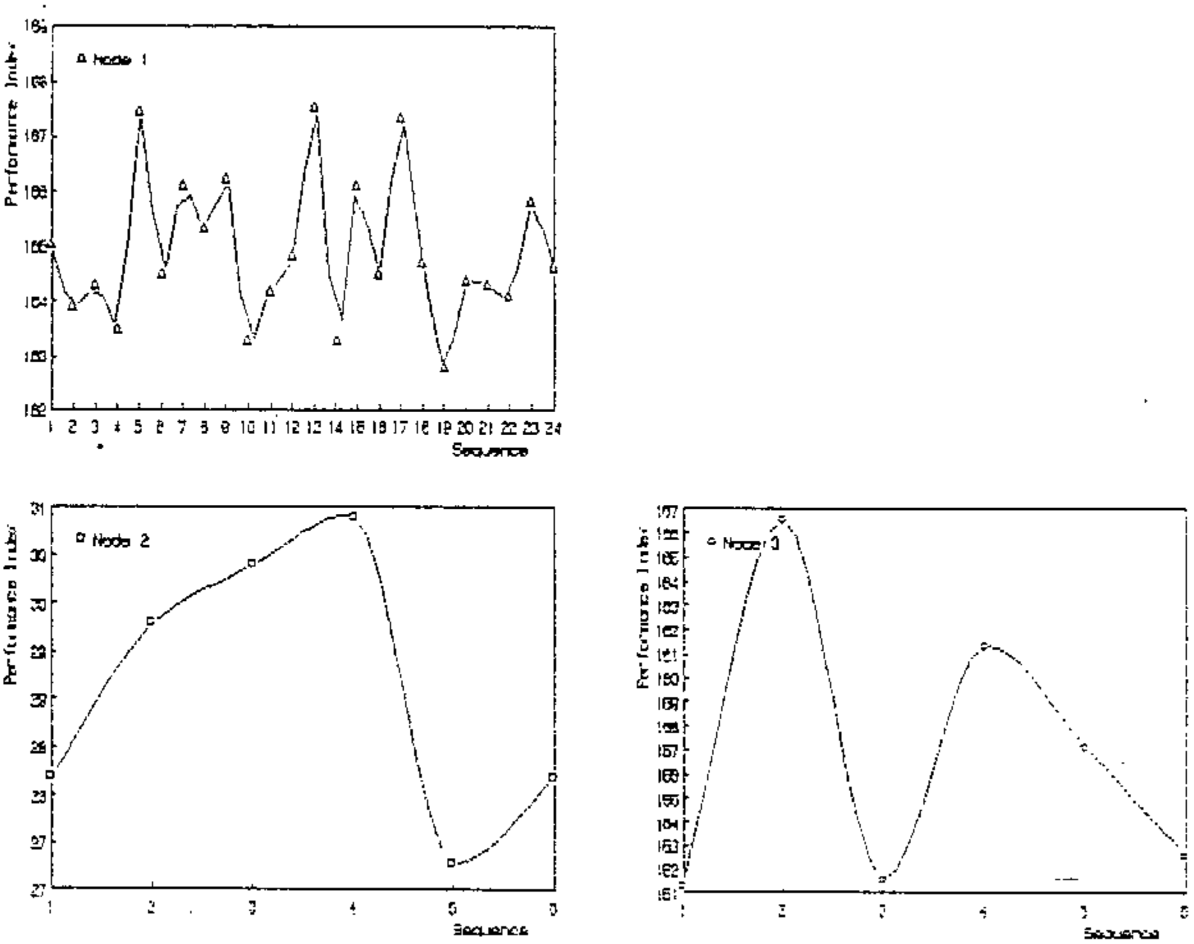


Fig 4.10 PI values versus phase sequences for each node (100 sec)

Phase Sequence	System Wide PI
19,5,1	346.93

```
*** Cycle Evaluation Using Phase Sequence 19,5,1
                    ----------------------------------
                    CYCLE EVALUATION SUMMARY PERFORMANCE            DATE OF RUN: 12/26/90  START TIME OF RUN:   14:47:41
                    ----------------------------------
 CYCLE    STEP    AVERAGE  PERCENT      FUEL        PERFORMANCE  NUMBER
 LENGTH   SIZE     DELAY    STOPS    CONSUMPTION      INDEX     SATURATED
 (SEC)  (STEPS)  (SEC/VEH)   (%)      (GAL/HR)                    LINKS
------------------------------------------------------------------------
   90      30     182.86      65       1712.7         363.2        21
   95      32     177.36      65       1673.5         352.9        22
  100      33     176.33      66       1667.6         351.3        22
  105      35     173.69      63       1645.4         345.4        22
  110      37     173.15      64       1642.9         344.8        22       BEST CYCLE LENGTH = 120 SEC.
  115      38     174.30      65       1652.3         347.2        22
  120      40     172.25      63       1634.8         342.6        21
  125      42     173.21      64       1642.9         344.8        21
  130      43     174.57      64       1652.8         347.4        22
------------------------------------------------------------------------

<PERFORMANCE WITH OPTIMAL SETTINGS>                                             CYCLE:  120 SECONDS
  NODE LINK   FLOW    SAT   DEGREE   TOTAL      TOTAL    -------- DELAY --------  AVERAGE    UNIFORM     MAX BACK   QUEUE      FUEL   PHASE   LINK
  NO.   NO.          FLOW   OF SAT   TRAVEL     TIME     UNIFORM  RANDOM   TOTAL   DELAY      STOPS      OF QUEUE  CAPACITY  CONSUM  LENGTH   NO.
             (VEH/H)(VEH/H)  (%)   (VEH-KM/H)(VEH-H/H)        (VEH-H/H)         (SEC/VEH) (VEH/H;%)  (VEH/LK)  (VEH/LK)  (LI/H)  (SEC)

   1    101     10  1900P   134*       2.00      .80      .17      .65     .82   296.5      7.5( 75%)    19          26     2.72     16     101
   1    102    190  1015    134*      38.00    16.73     3.27    12.36   15.65   296.5    142.3( 75%)   101        1015    49.22     16     102
   1    103     96  1015    134*      19.20     8.45     1.65     6.25    7.91   296.5     71.9( 75%)   101        1015    24.87     16     103
   1    104     66  1880P   135*      13.20     6.15     1.40     4.37    5.77   315.0     49.0( 74%)    25          26    18.03     20     104
   1    105     50  1045    135*      10.00     4.66     1.06     3.31    4.37   315.0     37.1( 74%)   104        1045    13.66     20     105
   1    106    264  1045    135*      52.80    24.61     5.60    17.50   23.10   315.0    195.9( 74%)   104        1045    72.13     20     106
   1    107    844  1950P   165*     337.60   108.43    15.49    83.30   98.79   421.4    511.9( 61%)    77    >    53C   317.49     45     107
   1    108     38  1075    165*      15.20     4.80      .70     3.75    4.45   421.4     23.0( 61%)   107        1075    14.29     45     108
   1    109    270  1075    165*     108.00    34.69     4.95    26.65   31.50   421.4    165.8( 61%)   107        1075   101.57     45     109
   1    110    540  2250P   107*     230.04    21.48     4.23    10.83   15.06   100.4    455.9( 84%)    35          56    72.63     39     110
   1    111     34  1105    107*      14.48     1.34      .24      .68     .92    97.6     28.0( 82%)   110        1105     4.49     39     111
   1    112    168  1105    107*      71.57     6.62     1.21     3.37    4.58    98.1    141.1( 84%)   110        1105    22.29     39     112

   1 :          2570   MAX = 165*    912.09   238.92    39.97   173.05  213.02   298.4   1827.4( 71%)                     713.40  PI =   161.4

   2    201    850  2420     96*     340.00    22.00     8.53     3.75   12.28    52.0    787.9( 93%)    27          53    80.97     46     201
   2    202  . 100  1200      8       40.00     1.14      .00      .00     .00      .0       .0(  0%)     0          53     4.50    120     202
   2    204    884  2075     71      376.58    14.11     3.19      .43    3.52    14.7    319.6( 36%)    11          56    55.66     74     204
   2    205    376  1100    105*     160.18    15.66     3.65     7.44   11.09   106.2    223.5( 59%)     7          56    51.22     41     205
   2    206    558  2215     98*      98.77    13.41     6.55     4.15   10.70    69.1    531.0( 95%)    18          23    46.95     33     206
   2    207    256  1200     21       45.31     1.23      .00      .00     .00      .0       .0(  0%)     0          23     5.10    120     207

   2 :          3024   MAX = 105*   1060.84    67.62    21.91    15.76   37.59    44.9   1862.0( 62%)                     244.40  PI =    33.2

   3    301    160  1950P   154*      48.00    18.73     3.34    14.08   17.42   391.9    104.2( 65%)    42    >    39C    54.84     27     301
   3    302    250  1200     21       75.00     2.14      .00      .00     .00      .0       .0(  0%)     0          39     8.44    120     302
   3    303    464  3015    154*     139.20    54.49     9.69    40.82   50.51   391.9    302.1( 65%)   301        3015   159.03     27     303
   3    304    226  1100P   215*     135.60    41.54     7.33    30.33   37.56   600.0    105.2( 47%)    26          79   120.83     22     304
   3    305    112  3045    215*      67.20    20.53     3.63    15.03   18.67   600.0     52.1( 47%)   304        3045    59.88     22     305
   3    306     56  3045    215*      33.60    10.29     1.82     7.52    9.33   600.0     26.1( 47%)   304        3045    29.94     22     306
   3    307   1358  2150P   119*     240.37    64.16     3.32    54.41   57.74   153.1    898.4( 66%)    34    >    23C   197.65     71     307
   3    308    108  3075    119*      19.12     5.19      .32     4.33    4.64   154.8     44.7( 41%)   307        3075    15.52     71     308
   3    309    854  2150P    77      256.20    12.49     4.61      .57    5.17    21.8    614.7( 72%)    24          39    49.92     71     309
   3    310     96  3095     77       28.80     1.40      .52      .06     .58    21.8     69.1( 72%)   309        3095     5.61     71     310

   3 :          3684   MAX = 215*   1043.08   231.08    34.58   167.15  201.73   197.1   2216.6( 60%)                     701.67  PI =   154.6

                                                  <SYSTEM WIDE TOTALS INCLUDING ALL LINKS>
   TOTAL       TOTAL      TOTAL       TOTAL      TOTAL      AVERAGE      TOTAL        TOTAL
  DISTANCE     TRAVEL    UNIFORM     RANDOM      DELAY       DELAY      UNIFORM        FUEL      OPERATING PERFORMANCE  SPEED
  TRAVELED      TIME      DELAY       DELAY                              STOPS        CONSUM       COST       INDEX
 (VEH-KM/H)  (VEH-H/H)  (VEH-H/H)  (VEH-H/H)  (VEH-H/H)  (SEC/VEH)    (VEH/H-%)      (LI/H)                            (KM/H)

  3016.01      537.62      96.46 .    355.97     452.44     175.55     5906.0( 64%)  1659.46     2156.58    (349.14)       5.61 <TOTALS>
<ROUTE SUMMARY REPORT>    THE TSD ORIENTATION DOWNBOUND ON THE PAGE IS WESTBOUND

  NODE LINK   FLOW    SAT   DEGREE   TOTAL      TOTAL    -------- DELAY --------  AVERAGE    UNIFORM     MAX BACK   QUEUE      FUEL   PHASE   LINK
  NO.   NO.          FLOW   OF SAT   TRAVEL     TIME     UNIFORM  RANDOM   TOTAL   DELAY      STOPS      OF QUEUE  CAPACITY  CONSUM  LENGTH   NO
             (VEH/H)(VEH/H)  (%)   (VEH-KM/H)(VEH-H/H)        (VEH-H/H)         (SEC/VEH) (VEH/H;%)  (VEH/LK)  (VEH/LK)  (LI/H)  (SEC)

   1    107    844  1950P   165*     337.60   108.43    15.49    83.30   98.79   421.4    511.9( 61%)    77    >    53C   317.49     45     107
   2    204    884  2075     71      376.58    14.11     3.19      .43    3.62    14.7    319.6( 36%)    11          56    55.66     74     204
   3    307   1358  2150P   119*     240.37    64.16     3.32    54.41   57.74   153.1    898.4( 66%)    34    >    23C   197.65     71     307

DOWN    :       3086   MAX = 165*    954.55   186.70    22.00   138.14  160.14   166.8   1730.0( 56%)                     570.79  PI =   122.7

   1    110    540  2250P   107*     230.04    21.48     4.23    10.83   15.06   100.4    455.9( 84%)    35          56    72.63     39     110
   2    206    558  2215     98*      98.77    13.41     6.55     4.15   10.70    69.1    551.0( 95%)    18          23    46.95     33     206
   3    309    854  2150P    77      256.20    12.49     4.61      .57    5.17    21.8    614.7( 72%)    24          39    49.92     71     309

UP      :       1952   MAX = 107*    585.01    47.38    15.38    15.55   30.33    57.0   1601.6( 82%)                     169.51  PI =    27.5

                                                  <ROUTE TOTALS>
   TOTAL       TOTAL      TOTAL       TOTAL      TOTAL      AVERAGE      TOTAL        TOTAL
  DISTANCE     TRAVEL    UNIFORM     RANDOM      DELAY       DELAY      UNIFORM        FUEL      OPERATING PERFORMANCE  SPEED
  TRAVELED      TIME      DELAY       DELAY                              STOPS        CONSUM       COST       INDEX
 (VEH-KM/H)  (VEH-H/H)  (VEH-H/H)  (VEH-H/H)  (VEH-H/H)  (SEC/VEH)    (VEH/H-%)      (LI/H)                            (KM/H)

  1539.56      234.08      37.38      153.69     191.08     136.54     3331.6( 66%)   740.50      941.79      150.25        6.58 <TOTALS>
```

Fig. 4.11 Optimal solution using phase sequence 19,5,1

ITERATION : 2

Input Cycle Length: 120 seconds

Resulting Sequence: 6,4,3

Resulting PI Value: 341.53

Best Cycle Length Over Range: 125 seconds

Resulting PI Value: 342.84

Reference: Table 4.4, Fig 4.12, Fig 4.13

Table 4.4 Resulting PI's for cycle length of 120 sec

Phase Sequence	Node			System Wide
	1	2	3	
1,1,1	164.2	30.4	176.8	371.49
2,2,2	161.4	32.4	161.9	355.7
3,3,3	164.7	36.6	149.2	350.57
4,4,4	163.1	29.1	149.8	341.99
5,5,5	162.4	33.2	146.4	342.07
6,6,6	161.2	33.1	147.6	341.91
7,6,1	167.6	34.1	174	375.65
8,1,2	169.5	29.3	162.3	361.05
9,2,3	175.9	32.7	150	358.58
10,3,4	177.8	36.3	149	363.1
11,4,5	165.6	28.9	150.1	344.63
12,5,6	167.8	34.7	151	353.51
13,6,1	179.2	33	168.6	380.75
14,5,2	164.4	32	161.2	357.5
15,4,3	171	28.3	145.9	345.27
16,3,4	165.1	37.1	152.9	355.14
17,2,5	163.7	36.3	148.1	348.03
18,6,1	163.6	32.5	168.8	364.96
19,5,2	161.4	33.1	161.8	356.21
20,1,6	171.6	29.5	148.3	349.47
21,2,1	163	35.8	171	369.8
22,3,2	162.2	33.4	162.1	357.65
23,4,3	167.9	28.6	147.3	343.72
24,5,4	177	33.2	148.4	358.67

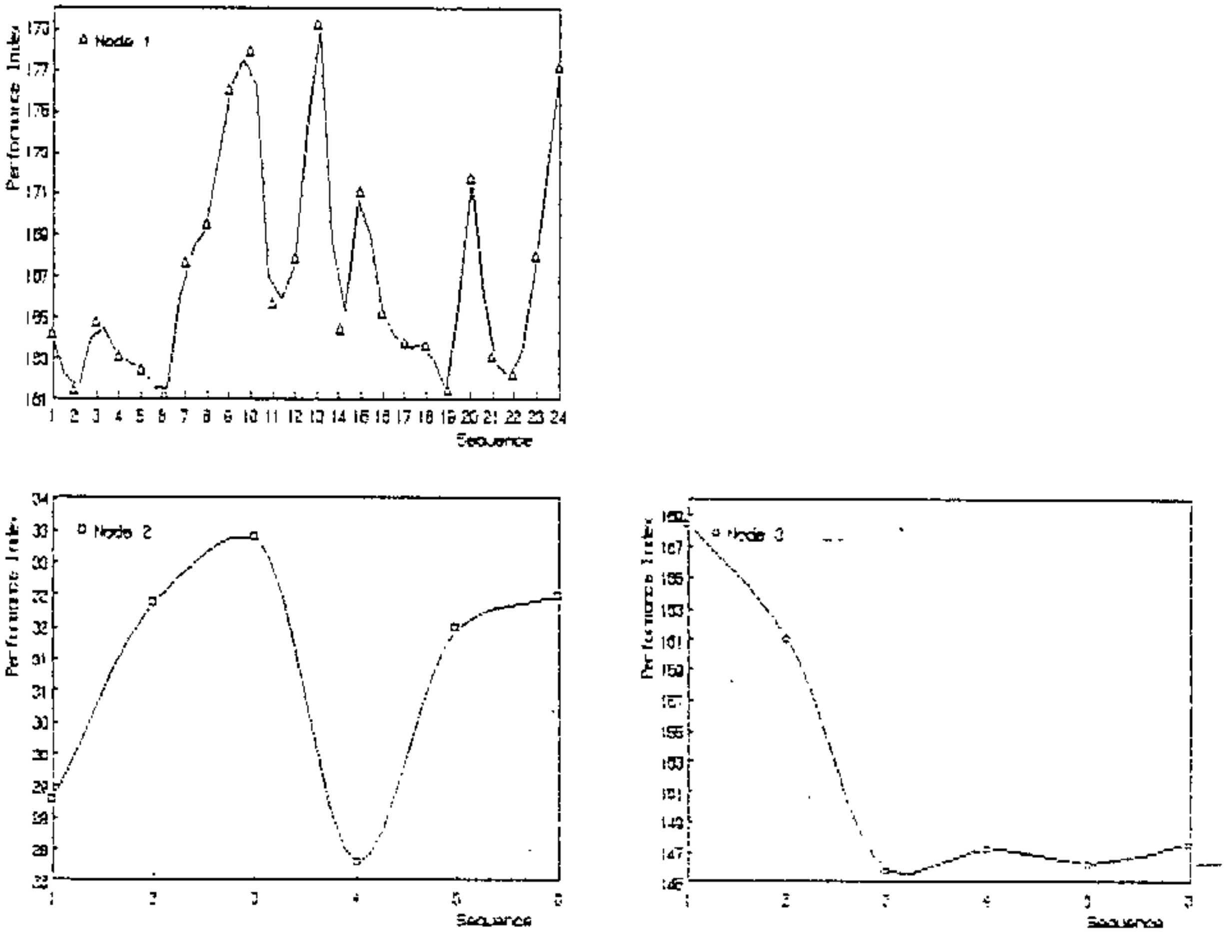


Fig 4.12 PI values versus phase sequences for each node (120 sec)

Phase Sequence	System Wide PI
6,4,3	341.53

```
*** Cycle Evaluation Using Phase Sequence 6,4,3
                        ------------------------------------
                        CYCLE EVALUATION SUMMARY PERFORMANCE
                        ------------------------------------          DATE OF RUN: 12/26/90   START TIME OF RUN:    14: 3: 1
  CYCLE    STEP    AVERAGE   PERCENT       FUEL       PERFORMANCE  NUMBER
 LENGTH    SIZE     DELAY     STOPS     CONSUMPTION      INDEX    SATURATED
  (SEC)  (STEPS)  (SEC/VEH)    (%)        (GAL/HR)                  LINKS
-------------------------------------------------------------------------
    90      30     180.16      63         1691.9         357.7       22
    95      32     181.06      65         1700.0         359.9       22
   100      33     177.28      64         1672.6         352.7       22
   105      35     176.19      64         1664.8         350.5       22
   110      37     176.45      65         1667.3         351.2       22          BEST CYCLE LENGTH = 125 SEC.
   115      38     173.82      63         1646.0         345.6       22
   120      40     174.41      63         1650.0         346.7       22
   125      42     172.54      61         1634.3         342.5       22
   130      43     172.66      63         1637.6         343.4       22
-------------------------------------------------------------------------

<PERFORMANCE WITH OPTIMAL SETTINGS>                                  CYCLE:   125 SECONDS,
   NODE LINK    FLOW     SAT   DEGREE   TOTAL       TOTAL    -------- DELAY --------  AVERAGE    UNIFORM   MAX BACK  QUEUE      FUEL   PHASE   LINK
   NO.   NO.            FLOW   OF SAT   TRAVEL      TIME     UNIFORM  RANDOM    TOTAL  DELAY      STOPS    OF QUEUE CAPACITY  CONSUM LENGTH   NO.
               (VEH/H) (VEH/H)  (%)   (VEH-KM/H) (VEH-H/H)          (VEH-H/H)        (SEC/VEH)  (VEH/H;%)  (VEH/LK)(VEH/LK)   (LI/H)  (SEC)

    1    101     10   1900P   122*      2.00       .74       .20      .48      .60   245.7      8.2( 82%)   18        26      2.34     18     101
    1    102    190   1015    122*     38.00     14.05      3.83     9.14    12.97   245.7    156.1( 82%)  101      1015     41.95     18     102
    1    103     96   1015    122*     19.20      7.10      1.94     4.62     6.55   245.7     78.9( 82%)  101      1015     21.19     18     103
    1    104     66   1880P   120*     13.20      4.42      1.06     2.96     4.04   220.3     54.9( 83%)   16        26     13.29     23     104
    1    105     50   1045    120*     10.00      3.35       .80     2.26     3.06   220.3     41.6( 83%)  104      1045     10.06     23     105
    1    106    264   1045    120*     52.80     17.66      4.23    11.92    16.15   220.3    219.4( 83%)  104      1045     53.14     23     106
    1    107    844   1950P   161*    337.60    105.23     15.72    79.86    95.58   407.7    525.7( 62%)   80   >   53C    308.76     48     107
    1    108     38   1075    161*     15.20      4.74       .71     3.60     4.30   407.7     23.7( 62%)  107      1075     13.90     48     108
    1    109    270   1075    161*    108.00     33.66      5.03    25.55    30.58   407.7    168.2( 62%)  107      1075     98.77     48     109
    1    110    540   2250P   121*    230.04     38.00      7.11    24.47    31.58   210.5    449.1( 83%)   48        56    118.34     36     110
    1    111     34   1105    121*     14.48      2.36       .41     1.54     1.95   206.3     27.0( 79%)  110      1105      7.33     36     111
    1    112    168   1105    121*     71.57     11.71      2.05     7.61     9.66   207.1    135.9( 81%)  110      1105     36.34     36     112

    1 :          2570   MAX = 161*    912.09    243.02     43.09   174.02   217.11   304.1   1080.6( 75%)                   725.41 PI =   164.6

    2    201    850   2420     95*    340.00     22.16      8.88     3.57    12.45    52.7    709.2( 93%)   29        53     81.45     48     201
    2    202    100   1200      8      40.00      1.14       .00      .00      .00      .0       .0(  0%)    0        53      4.50    125     202
    2    204    884   2075     71     376.58     14.37      3.45      .43     3.88    15.8    484.6( 55%)   17        56     58.28     77     204
    2    205    376   1100    104*    160.18     13.02      1.58     6.87     8.45    80.9    218.9( 58%)    8        56     43.85     43     205
    2    206    558   2215     98*     98.77     13.46      6.11     4.64    10.76    69.4    519.8( 93%)   18        23     46.97     34     206
    2    207    256   1200     21      45.31      1.29       .00      .00      .00      .0       .0(  0%)    0        23      5.10    125     207

    2 :          3024   MAX = 104*   1060.84     65.46     20.02    15.51    35.53    42.3   2012.5( 67%)                   240.15 PI =    32.1

    3    301    160   1950P   182*     48.00     23.33      3.88    18.08    21.96   434.1     88.0( 55%)   43   >   39C     67.25     24     301
    3    302    250   1200     21      75.00      2.14       .00      .00      .00      .0       .0(  0%)    0        39      8.44    125     302
    3    303    464   3015    182*    139.20     67.66     11.26    52.42    63.68   434.1    255.2( 55%)  301      3015    195.01     24     303
    3    304    226   1100P   249*    135.60     44.39      6.64    33.88    40.52   645.4     90.9( 40%)   27        79    128.58     20     304
    3    305    112   3045    249*     67.20     22.00      3.29    16.79    20.08   645.4     45.0( 40%)  304      3045     63.72     20     305
    3    306     56   3045    249*     33.60     11.00      1.64     8.40    10.04   645.4     22.5( 40%)  304      3045     31.86     20     306
    3    307   1358   2150P   108*    240.37     35.95      2.09    27.44    29.53    78.3    611.2( 45%)   28   >   23C    115.82     81     307
    3    308    108   3075    108*     19.12      2.96       .23     2.18     2.41    80.3     25.4( 24%)  307      3075      9.11     81     308
    3    309    854   2150P    70     256.20     11.15      3.47      .36     3.83    16.1    518.4( 61%)   21        39     45.15     81     309
    3    310     96   3095     70      28.80      1.25       .39      .04      .43    16.1     58.3( 61%)  309      3095      5.08     81     310

    3 :          3684   MAX = 249*   1043.08    221.83     32.88   159.59   192.47   188.1   1714.9( 47%)                   670.03 PI =   146.2
                                                <SYSTEM WIDE TOTALS INCLUDING ALL LINKS>
   TOTAL          TOTAL       TOTAL       TOTAL        TOTAL     AVERAGE        TOTAL          TOTAL
  DISTANCE        TRAVEL     UNIFORM      RANDOM       DELAY      DELAY        UNIFORM          FUEL      OPERATING  PERFORMANCE   SPEED
  TRAVELED        TIME        DELAY       DELAY                                 STOPS          CONSUM        COST        INDEX
 (VEH-KM/H)    (VEH-H/H)   (VEH-H/H)   (VEH-H/H)   (VEH-H/H)  (SEC/VEH)     (VEH/H-%)       (LI/H)                               (KM/H)

  3016.01        530.30       95.99-      349.13      445.11     172.71     5616.1( 61%)     1635.59      2125.27      342.84        5.69 <TOTALS>
<ROUTE SUMMARY REPORT>     THE TSD ORIENTATION DOWNBOUND ON THE PAGE IS WESTBOUND

   NODE LINK    FLOW     SAT   DEGREE   TOTAL       TOTAL    -------- DELAY --------  AVERAGE    UNIFORM   MAX BACK  QUEUE      FUEL   PHASE   LINK
   NO.   NO.            FLOW   OF SAT   TRAVEL      TIME     UNIFORM  RANDOM    TOTAL  DELAY      STOPS    OF QUEUE CAPACITY  CONSUM LENGTH   NO
               (VEH/H) (VEH/H)  (%)   (VEH-KM/H) (VEH-H/H)          (VEH-H/H)        (SEC/VEH)  (VEH/H;%)  (VEH/LK)(VEH/LK)   (LI/H)  (SEC)

    1    107    844   1950P   161*    337.60    105.23     15.72    79.86    95.58   407.7    525.7( 62%)   80   >   53C    308.76     48     107
    2    204    884   2075     71     376.58     14.37      3.45      .43     3.88    15.6    484.6( 55%)   17        56     58.28     77     204
    3    307   1358   2150P   108*    240.37     35.95      2.09    27.44    29.53    78.3    611.2( 45%)   28   >   23C    115.82     81     307
DOWN     :       3086   MAX = 161*    954.55    155.55     21.26   107.73   128.59   150.5   1621.6( 53%)                   402.87 PI =    99.5

    1    110    540   2250P   121*    230.04     38.00      7.11    24.47    31.58   210.5    449.1( 83%)   48        56    118.34     36     110
    2    206    558   2215     98*     98.77     13.46      6.11     4.64    10.76    69.4    519.8( 93%)   18        23     46.97     34     206
    3    309    854   2150P    70     256.20     11.15      3.47      .36     3.83    16.1    518.4( 61%)   21        39     45.15     81     309

UP       :       1952   MAX = 121*    585.01     62.61     16.69    29.48    46.16    85.1   1487.4( 76%)                   210.46 PI =    38.3
                                                <ROUTE TOTALS>
   TOTAL          TOTAL       TOTAL       TOTAL        TOTAL     AVERAGE        TOTAL          TOTAL
  DISTANCE        TRAVEL     UNIFORM      RANDOM       DELAY      DELAY        UNIFORM          FUEL      OPERATING  PERFORMANCE   SPEED
  TRAVELED        TIME        DELAY       DELAY                                 STOPS          CONSUM        COST        INDEX
 (VEH-KM/H)    (VEH-H/H)   (VEH-H/H)   (VEH-H/H)   (VEH-H/H)  (SEC/VEH)     (VEH/H-%)       (LI/H)                               (KM/H)

  1539.56        218.16       37.95       137.21      175.15     125.16     3108.9( 62%)      695.55       834.65      137.04        7.06 <TOTALS>
```

Fig 4.13 Optimal solution using phase sequence 6,4,3

ITERATION : 3

Input Cycle Length: 125 seconds

Resulting Sequence: 2,1,3

Resulting PI Value: 339.53

Best Cycle Length Over Range: 125 seconds

Resulting PI Value: 337.22

Reference: Table 4.5, Fig 4.14, Fig 4.15

Table 4.5 Resulting PI's for cycle length of 125 sec

Phase Sequence	Node			System Wide
	1	2	3	
1,1,1	165.7	28.2	176.6	370.42
2,2,2	161.4	31.6	159.9	352.88
3,3,3	170.1	38.3	149.3	357.78
4,4,4	162.6	31.4	148	342.05
5,5,5	167.6	31.8	150.5	349.78
6,6,6	163.3	31.3	147.5	342.03
7,6,1	167	36.6	177.8	381.5
8,1,2	167.5	27.6	167	362.16
9,2,3	182.2	32	148.3	362.59
10,3,4	178.3	45.1	147.2	370.64
11,4,5	164.9	30.7	147.7	343.34
12,5,6	167.6	35.6	152	355.27
13,6,1	185.1	30.9	171.2	387.22
14,5,2	170	33.7	158.3	362
15,4,3	172.7	29.5	145.5	347.8
16,3,4	164.3	38.5	152.4	355.23
17,2,5	166.3	38.3	148.4	353.04
18,6,1	163.7	34.9	173	371.61
19,5,2	162.5	34.6	160	357.17
20,1,6	177.2	29.8	147.6	354.54
21,2,1	163.9	35	174.7	373.58
22,3,2	162.1	35.1	164.3	361.55
23,4,3	171.5	29.8	145.3	346.69
24,5,4	177.9	33.6	145.7	357.24

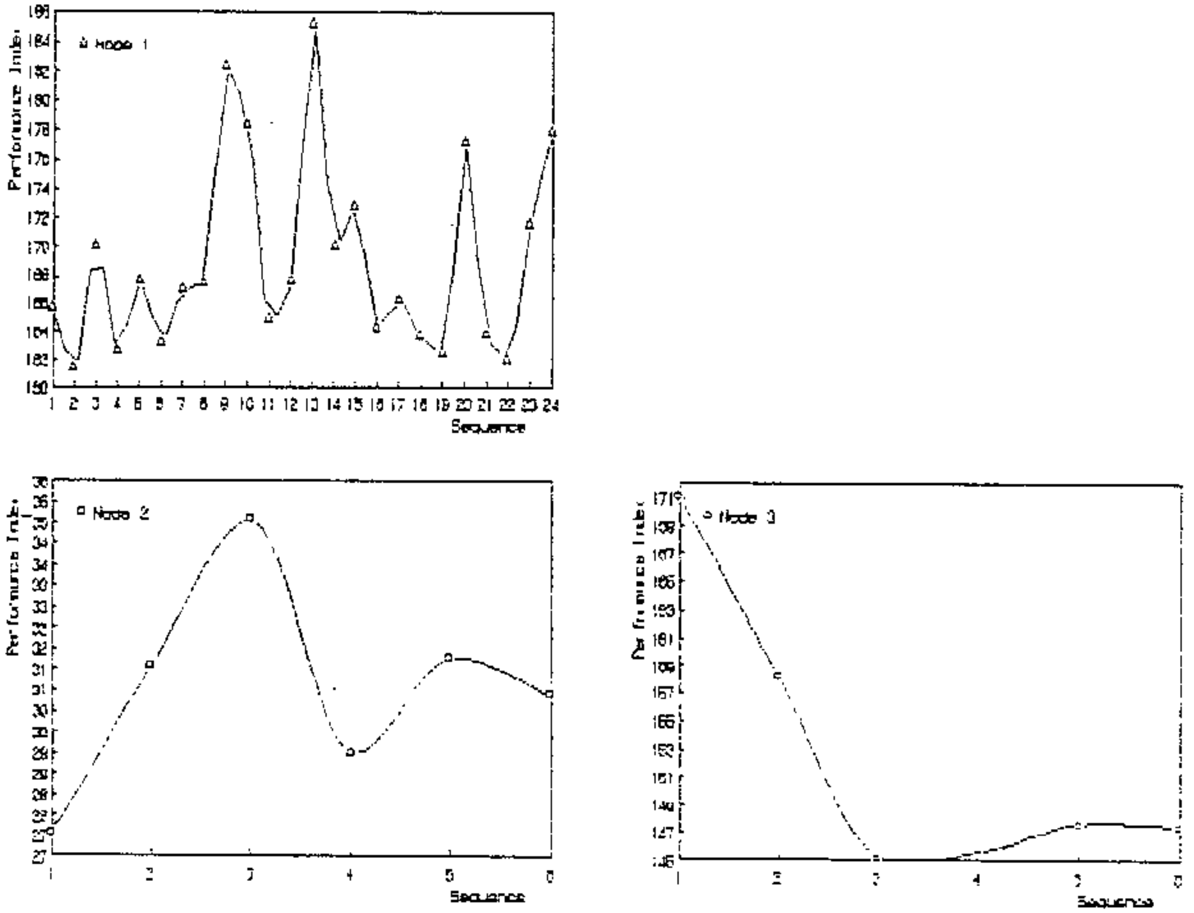


Fig 4.14 PI values versus phase sequences for each node (125 sec)

Phase Sequence	System Wide PI
2,1,3	339.53

```
*** Cycle Evaluation Using Phase Sequence 2,1,3
                    ----------------------------------------
                    CYCLE EVALUATION SUMMARY PERFORMANCE
                    ----------------------------------------          DATE OF RUN: 12/26/90  START TIME OF RUN:   13:11:13
 CYCLE   STEP    AVERAGE   PERCENT      FUEL       PERFORMANCE  NUMBER
LENGTH   SIZE     DELAY     STOPS    CONSUMPTION     INDEX    SATURATED
 (SEC) (STEPS) (SEC/VEH)     (%)       (GAL/HR)                  LINKS
--------------------------------------------------------------------------
   90     30     181.94      63        1704.4        361.0        22
   95     32     177.83      62        1673.5        352.9        22
  100     33     177.22      60        1666.8        351.1        22
  105     35     173.61      54        1635.1        342.7        21
  110     37     172.85      55        1630.5        341.5        21
  115     38     172.05      53        1622.1        339.3        22            BEST CYCLE LENGTH = 125 SEC.
  120     40     171.88      54        1622.1        339.3        21
  125     42     170.65      54      - 1613.4        337.0        21
  130     43     171.67      54        1620.7        336.9        20
--------------------------------------------------------------------------

<PERFORMANCE WITH OPTIMAL SETTINGS>                               CYCLE:  125 SECONDS,
  NODE LINK    FLOW    SAT   DEGREE    TOTAL      TOTAL   --------- DELAY ---------  AVERAGE    UNIFORM    MAX BACK  QUEUE     FUEL   PHASE  LINK
   NO.  NO.            FLOW  OF SAT   TRAVEL      TIME    UNIFORM  RANDOM   TOTAL    DELAY      STOPS     OF QUEUE CAPACITY  CONSUM LENGTH  NO.
             (VEH/H)(VEH/H)  (%)   (VEH-KM/H)(VEH-H/H)          (VEH-H/H)        (SEC/VEH) (VEH/H;%)  (VEH/LK)(VEH/LK)  (LI/H)  (SEC)

    1   101     10   1900P   150*      2.00      1.11      .20      .85     1.05   378.6     6.7( 67%)     14        26    3.34     15   101
    1   102    190   1015    150*     38.00     21.08     3.89    16.10    19.99   378.6   126.6( 67%)    101      1015   61.09     15   102
    1   103     96   1015    150*     19.20     10.65     1.97     8.13    10.10   378.6    64.1( 67%)    101      1015   30.87     15   103
    1   104     66   1880P   166*     13.20      8.66     1.52     6.77     8.29   452.1    39.2( 59%)     20        26   24.89     17   104
    1   105     50   1045    168*     10.00      6.56     1.15     5.13     6.28   452.1    29.7( 59%)    104      1045   18.86     17   105
    1   106    264   1045    168*     52.80     34.66     6.09    27.07    33.15   452.1   156.7( 59%)    104      1045   99.57     17   106
    1   107    844   1950P   151*    337.60     98.27    17.27    71.35    88.62   378.0   560.0( 66%)     66   >   53C  289.84     51   107
    1   108     38   1075    151*     15.20      4.42      .78     3.21     3.99   378.0    25.2( 66%)    107      1075   13.05     51   108
    1   109    270   1075    151*    108.00     31.44     5.53    22.83    28.35   378.0   179.2( 66%)    107      1075   92.72     51   109
    1   110    540   2250P   103*    230.04     17.19     3.60     7.17    10.77    71.6   511.9( 95%)     25        56   61.37     42   110
    1   111     34   1105    103*     14.48      1.06      .20      .45      .65    68.8    31.6( 93%)    110      1105    3.78     42   111
    1   112    168   1105    103*     71.57      5.27     1.00     2.23     3.23    69.1   159.2( 95%)    110      1105   18.75     42   112

    1 :         2570    MAX = 168*    912.09    240.38    43.19   171.20   214.47   300.4  1890.2( 74%)                    718.14 PI =  162.6

    2   201    850   2420     95*    340.00     22.20     8.91     3.57    12.48    52.9   790.8( 93%)     29        53   81.57     48   201
    2   202    100   1200      8      40.00      1.14      .00      .00      .00      .0      .0(  0%)      0        53    4.50    125   202
    2   204    884   2075     71     376.58     12.62     1.70      .43     2.13     8.7   167.2( 19%)      6        56   49.77     77   204
    2   205    376   1100    104*    160.18     12.47     1.03     6.87     7.89    75.5   134.3( 36%)      6        56   41.38     43   205
    2   206    558   2215     98*     98.77     12.82     5.48     4.64    10.12    65.3   510.9( 92%)     18        23   45.10     34   206
    2   207    256   1200     21      45.31      1.29      .00      .00      .00      .0      .0(  0%)      0        23    5.10    125   207

    2 :         3024    MAX = 104*   1060.84     62.55    17.11    15.51    32.63    38.8  1603.2( 53%)                    227.41 PI =   28.7

    3   301    160   1950P   182*     48.00     23.23     3.78    18.08    21.86   491.9    68.0( 59%)     43   >   39C   66.98     24   301
    3   302    250   1200     21      75.00      2.14      .00      .00      .00      .0      .0(  0%)      0        39    8.44    125   302
    3   303    464   3015    182*    139.20     67.37    10.97    52.42    63.40   491.9   265.2( 55%)    301      3015  154.23     24   303
    3   304    226   1100P   249*    135.60     44.31     6.55    33.88    40.43   644.0    90.9( 40%)     22        79  128.35     20   304
    3   305    112   3045    249*     67.20     21.96     3.25    16.79    20.04   644.0    45.0( 40%)    304      3045   63.61     20   305
    3   306     56   3045    249*     33.60     10.98     1.62     8.40    10.02   644.0    22.5( 40%)    304      3045   31.80     20   306
    3   307   1358   2150P   108*    240.37     36.76     2.90    27.44    30.34    80.4   400.0( 29%)     17        23  115.41     81   307
    3   308    108   3075    108*     19.12      3.11      .38     2.18     2.57    85.5    58.0( 54%)    307      3075    9.90     81   308
    3   309    854   2150P    70     256.20     11.12     3.43      .36     3.80    16.0   515.8( 60%)     21        39   45.03     81   309
    3   310     96   3095     70      28.80      1.25      .39      .04      .43    16.0    58.0( 60%)    309      3095    5.06     81   310

    3 :         3684    MAX = 249*   1043.08    222.22    33.28   159.59   192.87   188.5  1533.4( 42%)                    668.80 PI =  145.9

                                              <SYSTEM WIDE TOTALS INCLUDING ALL LINKS>
   TOTAL        TOTAL      TOTAL      TOTAL      TOTAL    AVERAGE      TOTAL       TOTAL
 DISTANCE      TRAVEL     UNIFORM     RANDOM     DELAY     DELAY      UNIFORM       FUEL    OPERATING PERFORMANCE  SPEED
 TRAVELED       TIME       DELAY      DELAY                            STOPS       CONSUM      COST       INDEX
(VEH-KM/H)  (VEH-H/H)  (VEH-H/H)  (VEH-H/H)  (VEH-H/H)  (SEC/VEH)   (VEH/H-%)      (LI/H)                          (KM/H)

 3016.01      525.15      93.58     346.38     439.97     170.71   5026.8( 54%)   1614.35    2095.22     337.22      5.74 <TOTALS>
<ROUTE SUMMARY REPORT>      THE TSD ORIENTATION DOWNBOUND ON THE PAGE IS WESTBOUND

  NODE LINK    FLOW    SAT   DEGREE    TOTAL      TOTAL   --------- DELAY ---------  AVERAGE    UNIFORM    MAX BACK  QUEUE     FUEL   PHASE  LINK
   NO.  NO.            FLOW  OF SAT   TRAVEL      TIME    UNIFORM  RANDOM   TOTAL    DELAY      STOPS     OF QUEUE CAPACITY  CONSUM LENGTH  NO
             (VEH/H)(VEH/H)  (%)   (VEH-KM/H)(VEH-H/H)          (VEH-H/H)        (SEC/VEH) (VEH/H;%)  (VEH/LK)(VEH/LK)  (LI/H)  (SEC)

    1   107    844   1950P   151*    337.60     98.27    17.27    71.35    88.62   378.0   560.0( 66%)     66   >   53C  289.84     51   107
    2   204    884   2075     71     376.58     12.62     1.70      .43     2.13     8.7   167.2( 19%)      6        56   49.77     77   204
    3   307   1358   2150P   108*    240.37     36.76     2.90    27.44    30.34    80.4   400.0( 29%)     17        23  115.41     81   307

 DOWN   :       3086    MAX = 151*    954.55    147.65    21.67    99.22   121.09   141.3  1127.2( 37%)                    455.01 PI =   92.2

    1   110    540   2250P   103*    230.04     17.19     3.60     7.17    10.77    71.8   511.9( 95%)     25        56   61.37     42   110
    2   206    558   2215     98*     98.77     12.82     5.48     4.64    10.12    65.3   510.9( 92%)     16        23   45.10     34   206
    3   309    854   2150P    70     256.20     11.12     3.43      .36     3.80    16.0   515.8( 60%)     21        39   45.03     81   309

 UP     :       1952    MAX = 103*    585.01     41.13    12.51    12.18    24.68    45.5  1538.6( 75%)                    151.50 PI =   22.8

                                              <ROUTE TOTALS>
   TOTAL        TOTAL      TOTAL      TOTAL-     TOTAL    AVERAGE      TOTAL       TOTAL
 DISTANCE      TRAVEL     UNIFORM     RANDOM     DELAY     DELAY      UNIFORM       FUEL    OPERATING PERFORMANCE  SPEED
 TRAVELED       TIME       DELAY      DELAY                            STOPS       CONSUM      COST       INDEX
(VEH-KM/H)  (VEH-H/H)  (VEH-H/H)  (VEH-H/H)  (VEH-H/H)  (SEC/VEH)   (VEH/H-%)      (LI/H)                          (KM/H)

 1539.56      189.78      34.38     111.39     145.77     104.17   2665.8( 55%)    606.51     779.12      114.90      8.16 <TOTALS>
```

Fig.4.15 Optimal solution using phase sequence 2,1,3

(Check Iteration)

ITERATION : 4 (to test the algorithm)

Input Cycle Length: 115 seconds

Resulting Sequence: 19,1,3

Resulting PI Value: 339.35

Best Cycle Length Over Range: 125 seconds

Resulting PI Value: 337.84 (greater than iteration 3)

Reference: Table 4.6, Fig 4.16, Fig 4.17

Table 4.6 Resulting PI's for cycle length of 115 sec

Phase Sequence	Node			System Wide
	1	2	3	
1,1,1	165	28	168.7	361.69
2,2,2	162.2	33.2	165	360.42
3,3,3	166.2	35	150.7	351.89
4,4,4	163.5	29.2	151.3	343.96
5,5,5	165.1	29.9	150.4	345.37
6,6,6	161.1	31.1	148.5	340.63
7,6,1	167.2	32	168.2	367.45
8,1,2	166.6	27.5	168.6	362.68
9,2,3	170	33.5	149.6	353.13
10,3,4	172.6	32.4	152	357
11,4,5	164	29.1	151.1	344.15
12,5,6	166.4	32.4	151.4	350.17
13,6,1	172.9	31.2	165.5	369.61
14,5,2	165	31.6	163.9	360.6
15,4,3	168.7	29.9	148.8	346.39
16,3,4	164	35	155	354.01
17,2,5	162.7	36.8	150	349.45
18,6,1	162.8	30.6	166.6	359.98
19,5,2	161.1	32.7	165	358.71
20,1,6	170.7	28.5	151.3	350.44
21,2,1	161.7	33.5	168.2	363.34
22,3,2	161.9	33.9	165.4	361.12
23,4,3	166.9	28.7	148.1	343.72
24,5,4	170.6	30.3	151	351.92

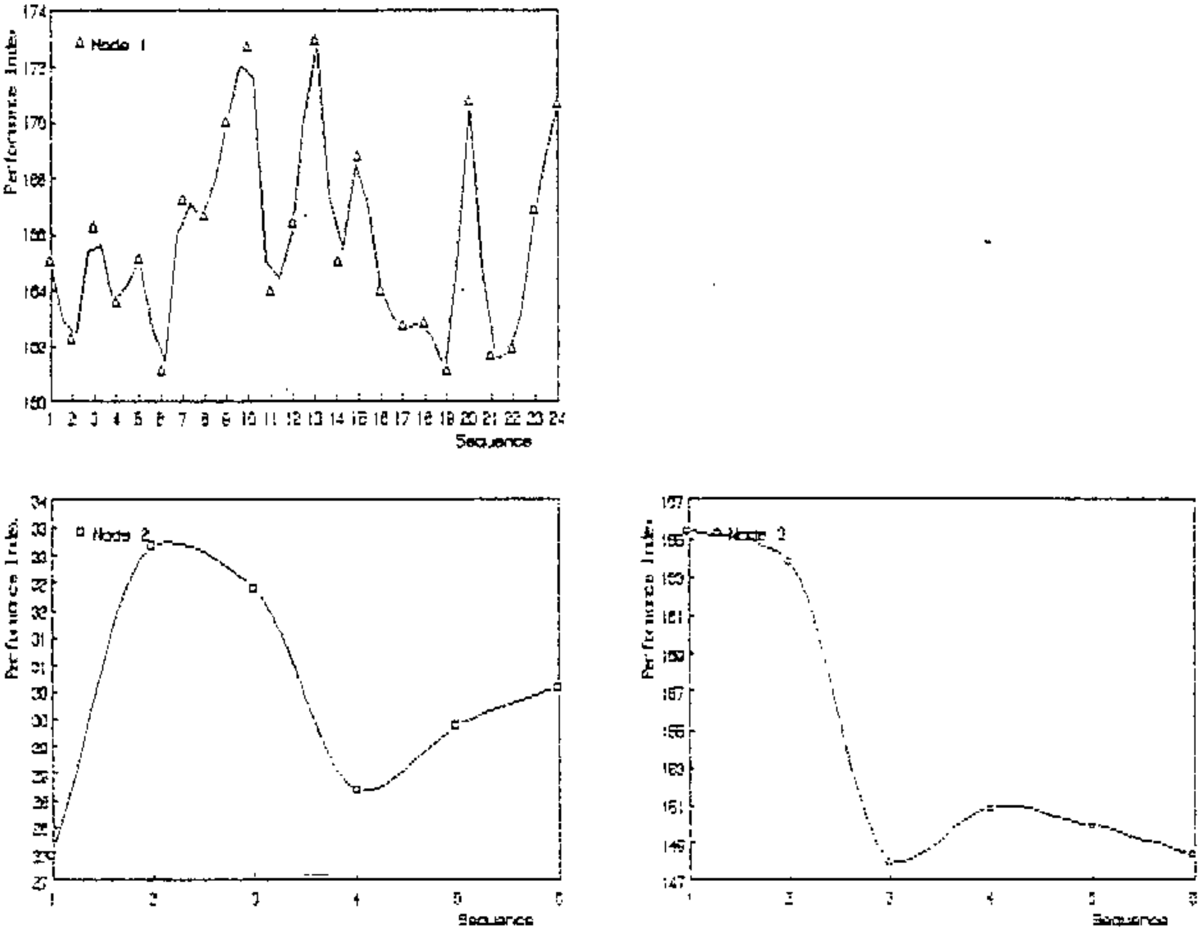


Fig 4.16 PI values versus phase sequences for each node (115 sec)

Phase Sequence	System Wide PI
19,1,3	339.35

```
*** Cycle Evaluation Using Phase Sequence 19,1,3
                          --------------------------------------
                          CYCLE EVALUATION SUMMARY PERFORMANCE          DATE OF RUN: 12/26/90   START TIME OF RUN:   15:39:10
                          --------------------------------------
 CYCLE     STEP     AVERAGE   PERCENT       FUEL       PERFORMANCE  NUMBER
LENGTH     SIZE      DELAY     STOPS    CONSUMPTION      INDEX     SATURATED
 (SEC)   (STEPS)  (SEC/VEH)     (%)       (GAL/HR)                   LINKS
-----------------------------------------------------------------------------
   90       30      181.92      63         1704.2         361.0        22
   95       32      178.10      58         1671.1         352.2        22
  100       33      177.12      59         1665.1         350.6        22          BEST CYCLE LENGTH = 125 SEC.
  105       35      173.35      54         1632.5         342.0        21
  110       37      172.90      54         1630.2         341.4        21
  115       38      171.44      52         1617.4         338.0        22
  120       40      171.63      53         1619.6         336.6        21
  125       42      170.81      53         1613.8         337.1        21
  130.      43      171.04      53         1615.1         337.4        22
-----------------------------------------------------------------------------
                                                                 |   CYCLE:   125 SECONDS,
<PERFORMANCE WITH OPTIMAL SETTINGS>                              |
  NODE LINK    FLOW    SAT   DEGREE   TOTAL       TOTAL    --------- DELAY ---------- AVERAGE    UNIFORM    MAX BACK  QUEUE     FUEL   PHASE  LINK
   NO.  NO.            FLOW  OF SAT   TRAVEL      TIME     UNIFORM  RANDOM    TOTAL    DELAY      STOPS     OF QUEUE CAPACITY  CONSUM LENGTH  NO.
              (VEH/H) (VEH/H)  (%)  (VEH-KM/H) (VEH-H/H)        (VEH-H/H)          (SEC/VEH) (VEH/H;%)  (VEH/LK) (VEH/LK)   (LI/H)  (SEC)

   1   101      10  1900P   139*       2.00        .98      .20      .72      .33    333.4      7.2( 72%)    15          26     3.00    16    101
   1   102     190  1015    139*      38.00      18.68     3.86    13.74    17.60    333.4    136.6( 72%)   101        1015    54.56    16    102
   1   103      96  1015    139*      19.20       9.44     1.95     6.94     8.99    333.4     69.0( 72%)   101        1015    27.57    16    103
   1   104      66  1080P   133*      13.20       5.77     1.17     4.22     5.39    294.0     49.6( 75%)    17          26    16.97    21    104
   1   105      50  1045    133*      10.00       4.37      .89     3.19     4.08    294.0     37.6( 75%)   104        1045    12.86    21    105
   1   106     264  1045    133*      52.80      23.07     4.69    16.87    21.56    294.0    198.5( 75%)   104        1045    67.89    21    106
   1   107     844  1950P   168*     337.60     113.77    18.58    85.55   104.12    444.1    502.9( 60%)    63   >     53C   332.18    46    107
   1   108      38  1075    168*      15.20       5.12      .84     3.05     4.59    444.1     22.6( 60%)   107        1075    14.96    46    108
   1   109     270  1075    168*     108.00      36.40     5.94    27.37    33.31    444.1    160.9( 60%)   107        1075   106.27    46    109
   1   110     540  2250P   103*     230.04      17.00     3.41     7.17    10.58     70.5    509.9( 94%)    25          56    60.83    42    110
   1   111      34  1105    103*      14.48       1.05      .18      .45      .64     67.3     31.5( 93%)   110        1105     3.74    42    111
   1   112     168  1105    103*      71.57       5.20      .92     2.23     3.16     67.6    158.4( 94%)   110        1105    18.54    42    112

   1 :        2570    MAX = 168*     912.09     240.04    42.63   172.30   214.93    301.1   1884.7( 73%)                    719.37 PI =  163.0

   2   201     850  2420     95*     340.00      22.07     8.78     3.57    12.35     52.3    785.0( 92%)    28          53    81.15    48    201
   2   202     100  1200      8       40.00       1.14      .00      .00      .00       .0       .0(  0%)     0          53     4.50   125    202
   2   204     884  2075     71      376.58      11.98     1.05      .43     1.48      6.0    104.0( 12%)     4          56    47.24    77    204
   2   205     376  1100    104*     160.18      12.22      .78     6.87     7.65     73.2    136.1( 36%)     5          56    40.72    43    205
   2   206     558  2215     98*      98.77      12.94     5.59     4.64    10.24     66.1    514.8( 92%)    18          23    45.46    34    206
   2   207     256  1200     21       45.31       1.29      .00      .00      .00       .0       .0(  0%)     0          23     5.10   125    207

   2 :        3024    MAX = 104*    1060.84      61.65    16.21    15.51    31.72     37.8   1539.8( 51%)                    224.18 PI =   27.9

   3   301     160  1950P   182*      48.00      23.60     4.15    18.06    22.23    500.1     88.0( 55%)    43   >     39C    67.99    24    301
   3   302     250  1200     21       75.00       2.14      .00      .00      .00       .0       .0(  0%)     0          39     8.44   125    302
   3   303     464  3015    182*     139.20      68.44    12.03    52.42    64.46    500.1    255.2( 55%)   301        3015   197.17    24    303
   3   304     226  1100P   249*     135.60      44.67     6.91    33.88    40.79    649.8     90.9( 40%)    27          73   129.35    20    304
   3   305     112  3045    249*      67.20      22.14     3.43    16.79    20.22    649.8     45.0( 40%)   304        3045    64.10    20    305
   3   306      56  3045    249*      33.60      11.07     1.71     8.40    10.11    649.8     22.5( 40%)   304        3045    32.05    20    306
   3   307    1358  2150P   108*     240.37      36.45     2.59    27.44    30.03     79.6    373.3( 27%)    16          23   114.21    81    307
   3   308     108  3075    108*      19.12       3.02      .30     2.18     2.48     82.6     50.3( 47%)   307        3075     9.57    81    308
   3   309     854  2150P    70      256.20      11.15     3.47      .36     3.83     16.1    518.1( 61%)    21          39    45.14    81    309
   3   310      96  3095     70       28.80       1.25      .39      .04      .43     16.1     58.2( 61%)   309        3095     5.07    81    310

   3 :        3684    MAX = 249*    1043.08     223.92    34.98   159.59   194.57    190.1   1501.5( 41%)                    673.12 PI =  147.0

                                                  <SYSTEM WIDE TOTALS INCLUDING ALL LINKS>
    TOTAL        TOTAL      TOTAL       TOTAL        TOTAL     AVERAGE      TOTAL         TOTAL
  DISTANCE       TRAVEL    UNIFORM      RANDOM       DELAY      DELAY      UNIFORM         FUEL      OPERATING  PERFORMANCE   SPEED
  TRAVELED       TIME       DELAY       DELAY                               STOPS         CONSUM       COST        INDEX
 (VEH-KM/H)   (VEH-H/H)  (VEH-H/H)   (VEH-H/H)   (VEH-H/H)  (SEC/VEH)    (VEH/H-%)       (LI/H)                             (KM/H)

  3016.01       526.41      93.82      347.41      441.23     171.20     4926.0( 53%)   1616.66     2097.37     337.84        5.73 <TOTALS>

<ROUTE SUMMARY REPORT>     THE TSD ORIENTATION DOWNBOUND ON THE PAGE IS WESTBOUND

  NODE LINK    FLOW    SAT   DEGREE   TOTAL       TOTAL    --------- DELAY ---------- AVERAGE    UNIFORM    MAX BACK  QUEUE     FUEL   PHASE  LINK
   NO.  NO.            FLOW  OF SAT   TRAVEL      TIME     UNIFORM  RANDOM    TOTAL    DELAY      STOPS     OF QUEUE CAPACITY  CONSUM LENGTH  NO
              (VEH/H) (VEH/H)  (%)  (VEH-KM/H) (VEH-H/H)        (VEH-H/H)          (SEC/VEH) (VEH/H;%)  (VEH/LK) (VEH/LK)   (LI/H)  (SEC)

    1   107     844  1950P   168*     337.60     113.77    18.58    85.55   104.12    444.1    502.9( 60%)    63   >     53C   332.18    46    107
    2   204     884  2075     71      376.58      11.98     1.05      .43     1.48      6.0    104.0( 12%)     4          56    47.24    77    204
    3   307    1358  2150P   108*     240.37      36.45     2.59    27.44    30.03     79.6    373.3( 27%)    16          23   114.21    81    307

DOWN   :      3086    MAX = 168*     954.55     162.19    22.22   113.42   135.63    158.2    980.1( 32%)                    493.64 PI =  102.4

    1   110     540  2250P   103*     230.04      17.00     3.41     7.17    10.58     70.5    509.9( 94%)    25          56    60.83    42    110
    2   206     558  2215     98*      98.77      12.94     5.59     4.64    10.24     66.1    514.8( 92%)    18          23    45.46    34    206
    3   309     854  2150P    70      256.20      11.15     3.47      .36     3.83     16.1    518.1( 61%)    21          39    45.14    81    309

UP     :      1952    MAX = 103*     585.01      41.09    12.47    12.18    24.64     45.4   1542.8( 79%)                    151.44 PI =   22.7

                                                  <ROUTE TOTALS>
    TOTAL        TOTAL      TOTAL       TOTAL        TOTAL     AVERAGE      TOTAL         TOTAL
  DISTANCE       TRAVEL    UNIFORM      RANDOM       DELAY      DELAY      UNIFORM         FUEL      OPERATING  PERFORMANCE   SPEED
  TRAVELED       TIME       DELAY       DELAY                               STOPS         CONSUM       COST        INDEX
 (VEH-KM/H)   (VEH-H/H)  (VEH-H/H)   (VEH-H/H)   (VEH-H/H)  (SEC/VEH)    (VEH/H-%)       (LI/H)                             (KM/H)

  1533.56       203.28      34.69      125.59      160.28     114.53     2522.9( 50%)    645.07      927.23      125.09        7.57 <TOTALS>
```

Fig 4.17 Optimal solution using phase sequence 19,1,3

(Check Iteration)

ITERATION : 5 (to test the algorithm)

Input Cycle Length: 110 seconds

Resulting Sequence: 19,5,6

Resulting PI Value: 345.57

Best Cycle Length Over Range: 125 seconds

Resulting PI Value: 344.82 (greater than iteration 3)

Reference: Table 4.7, Fig 4.18, Fig 4.19

Table 4.7 Resulting PI's for cycle length of 110 sec

Phase Sequence	Node			System Wide
	1	2	3	
1,1,1	163.6	27.8	164.2	355.50
2,2,2	161.8	30.7	169.3	361.75
3,3,3	163.2	33.8	152.4	349.29
4,4,4	163.4	29.0	154.0	346.45
5,5,5	166.9	27.4	151.6	345.93
6,6,6	162.1	28.3	149.5	339.92
7,6,1	167.9	30.0	166.9	364.67
8,1,2	165.9	27.5	166.5	359.88
9,2,3	171.2	31.3	152.0	354.57
10,3,4	167.3	33.7	154.9	355.81
11,4,5	162.8	28.8	153.5	345.11
12,5,6	164.5	30.9	151.0	346.46
13,6,1	173.6	29.0	162.4	365...
14,5,2	162.3	30.6	162.7	355.52
15,4,3	165.6	28.4	149.0	343.03
16,3,4	165.1	31.5	157.4	354.08
17,2,5	163.7	34.4	151.3	349.42
18,6,1	163.1	28.3	163.1	354.51
19,5,2	161.1	31.0	169.5	361.58
20,1,6	164.0	28.0	147.4	339.40
21,2,1	161.9	31.3	164.5	357.63
22,3,2	163.3	32.5	163.4	359.29
23,4,3	164.9	27.8	148.7	341.37
24,5,4	165.7	28.7	153.8	348.29

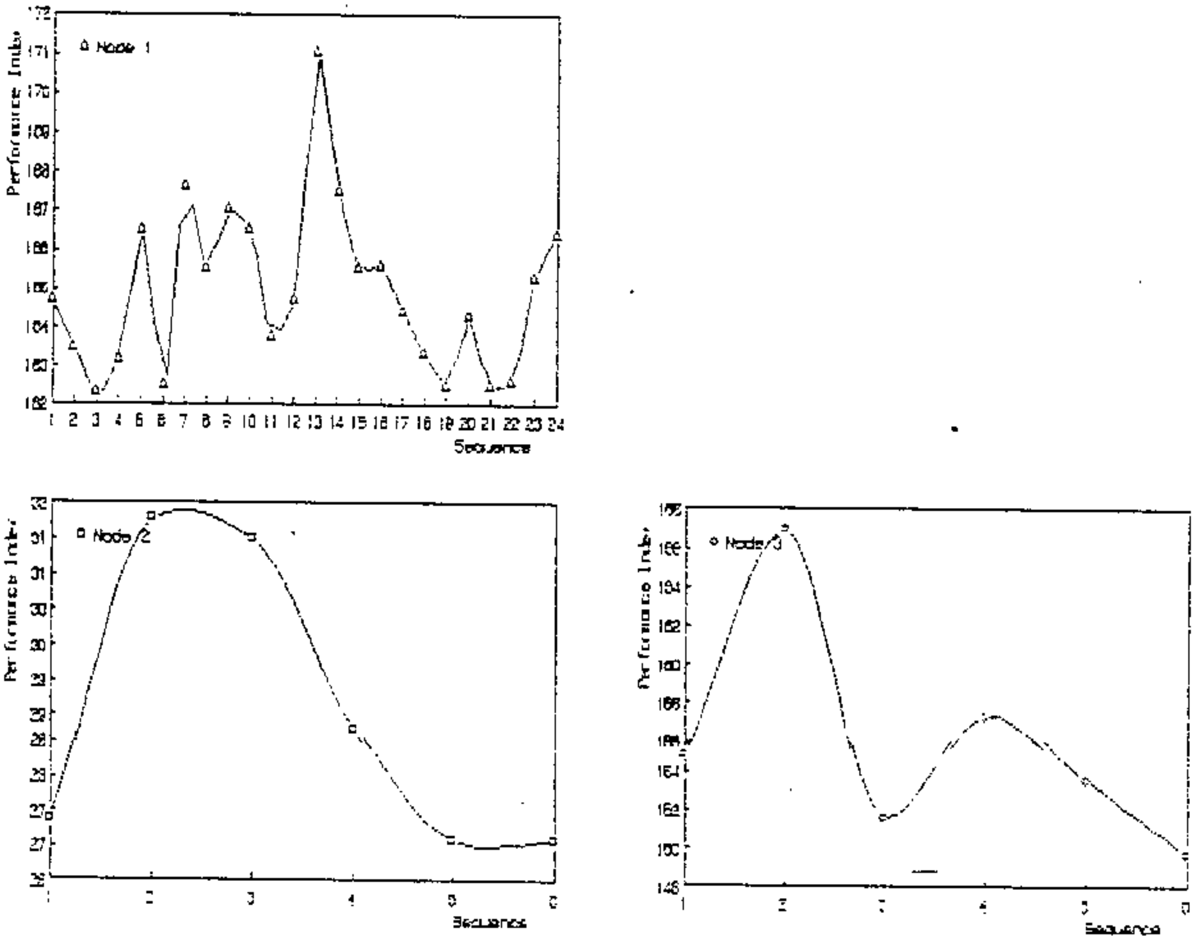
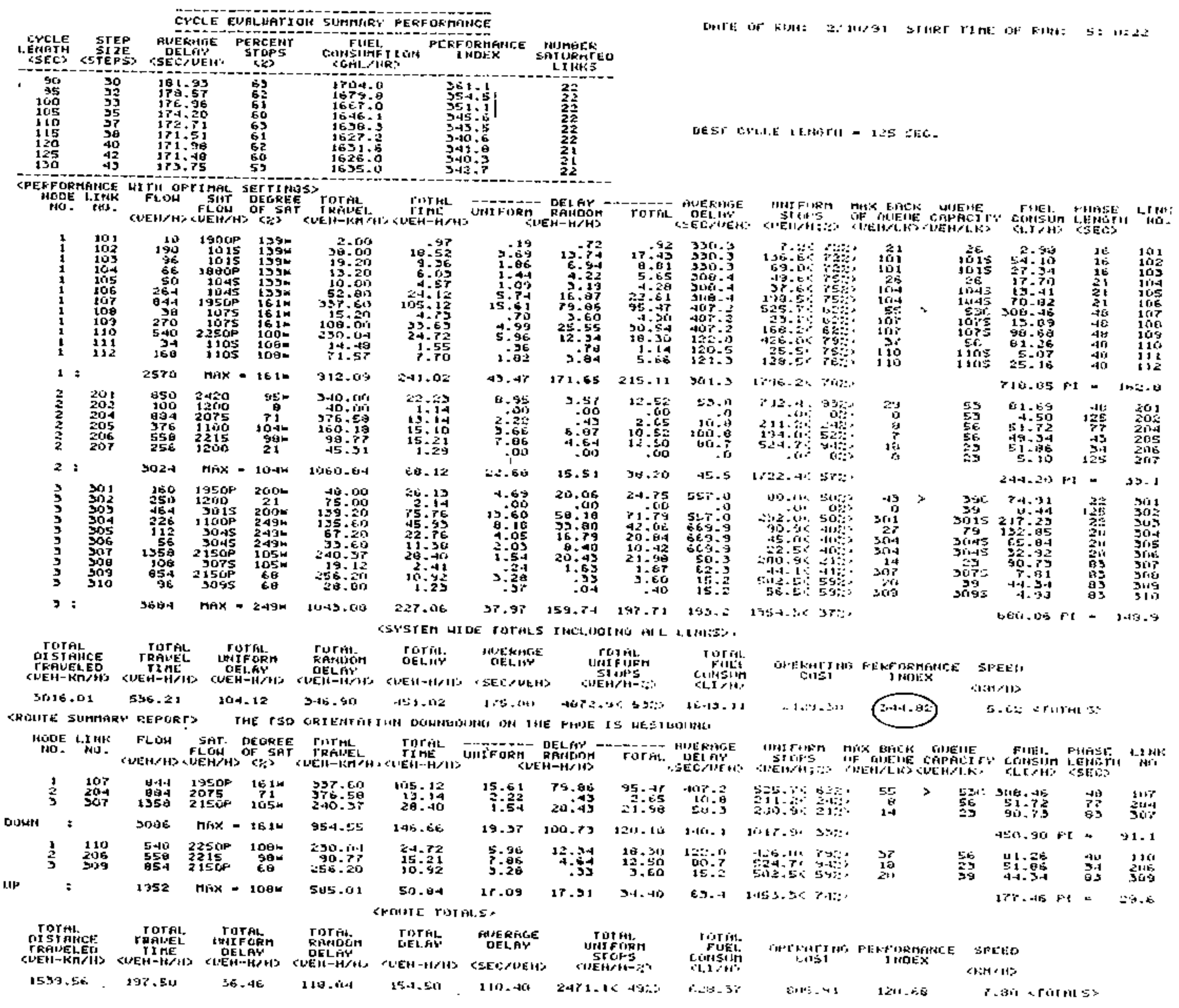


Fig 4.18 PI values versus phase sequences for each node (110 sec)

Phase Sequence	System Wide PI
19,5,6	345.57



```
                    ------------------------------------
                    CYCLE EVALUATION SUMMARY PERFORMANCE                          DATE OF RUN:  2/10/91   START TIME OF RUN:  5: 0:22
                    ------------------------------------
  CYCLE    STEP    AVERAGE  PERCENT       FUEL       PERFORMANCE  NUMBER
 LENGTH    SIZE     DELAY    STOPS     CONSUMPTION      INDEX     SATURATED
  (SEC)  (STEPS)  (SEC/VEH)   (%)        (GAL/HR)                   LINKS
-----------------------------------------------------------------------------
    90      30     181.93     63        1704.0         361.1         22
    95      32     178.57     62        1679.8         354.5         22
   100      33     176.96     61        1667.0         351.1         22
   105      35     174.20     60        1646.1         345.6         22
   110      37     172.71     63        1638.3         343.5         22          BEST CYCLE LENGTH = 125 SEC.
   115      38     171.51     61        1627.2         340.6         22
   120      40     171.98     62        1631.6         341.8         21
   125      42     171.48     60        1626.0         340.3         21
   130      43     173.75     55        1635.0         343.7         22
-----------------------------------------------------------------------------
<PERFORMANCE WITH OPTIMAL SETTINGS>
 NODE LINK   FLOW    SAT   DEGREE   TOTAL       TOTAL    -------- DELAY --------  AVERAGE    UNIFORM    MAX BACK   QUEUE      FUEL   PHASE   LINK
  NO.  NO.          FLOW   OF SAT   TRAVEL      TIME     UNIFORM  RANDOM   TOTAL   DELAY      STOPS     OF QUEUE CAPACITY   CONSUM  LENGTH   NO.
            (VEH/H)(VEH/H)  (%)   (VEH-KM/H)(VEH-H/H)        (VEH-H/H)          (SEC/VEH) (VEH/H;%)  (VEH/LK) (VEH/LK)   (LI/H)  (SEC)

   1   101     10  1900P   139*       2.00       .97      .19      .72      .92   330.3     7.2( 72%)     21         26      2.98     16     101
   1   102    190   101S   139*      38.00     18.52     3.69    13.74    17.43   330.3   136.6( 72%)    101       101S     54.10     16     102
   1   103     96   101S   139*      19.20      9.36     1.86     6.94     8.81   330.3    69.0( 72%)    101       101S     27.34     16     103
   1   104     66  1800P   133*      13.20      6.05     1.44     4.22     5.65   308.4    49.6( 75%)     26         26     17.70     21     104
   1   105     50   104S   133*      10.00      4.57     1.09     3.19     4.28   308.4    37.6( 75%)    104       1043     13.41     21     105
   1   106    264   104S   133*      52.80     24.12     5.74    16.87    22.61   308.4   198.5( 75%)    104       1045     70.82     21     106
   1   107    844  1950P   161*     337.60    105.12    15.61    79.86    95.47   407.2   525.7( 62%)     55  >      530    308.46     48     107
   1   108     38   107S   161*      15.20      4.73      .70     3.60     4.30   407.2    23.7( 62%)    107       107S     15.09     48     108
   1   109    270   107S   161*     108.00     33.63     4.99    25.55    30.54   407.2   168.2( 62%)    107       107S     98.68     48     109
   1   110    540  2250P   100*     230.04     24.72     5.96    12.34    18.30   122.0   426.0( 79%)     37         56     81.26     40     110
   1   111     34   110S   108*      14.48      1.55      .36      .78     1.14   120.5    25.5( 75%)    110       110S      5.07     40     111
   1   112    160   110S   108*      71.57      7.70     1.82     3.84     5.66   121.3   128.5( 76%)    110       110S     25.16     40     112

   1 :         2570   MAX = 161*     912.09    241.02    43.47   171.65   215.11   301.3  1796.2( 70%)                     710.05 PI =   162.8

   2   201    850  2420     95*     340.00     22.23     8.95     3.57    12.52    53.0   712.4( 93%)     29         55     81.69     40     201
   2   202    100  1200      8       40.00      1.14      .00      .00      .00      .0      .0(  0%)      0         53      4.50    125     202
   2   204    834  2075     71      376.58     13.14     2.20      .43     2.65    10.8   211.2( 24%)      8         56     51.72     77     204
   2   205    376  1100    104*     160.18     15.10     3.66     6.87    10.52   100.8   194.0( 52%)      7         56     49.34     45     205
   2   206    558  2215     98*      98.77     15.21     7.86     4.64    12.50    60.7   524.7( 94%)     18         23     51.86     34     206
   2   207    256  1200     21       45.31      1.29      .00      .00      .00      .0      .0(  0%)      0         23      5.10    125     207

   2 :         3024   MAX = 104*    1060.64     68.12    22.68    15.51    38.20    45.5  1722.4( 57%)                     244.20 PI =    35.1

   3   301    160  1950P   200*      40.00     26.13     4.69    20.06    24.75   557.0    80.0( 50%)     43  >      390     74.31     22     301
   3   302    250  1200     21       75.00      2.14      .00      .00      .00      .0      .0(  0%)      0         39      0.44    125     302
   3   303    464   301S   200*     139.20     75.76    13.60    58.18    71.79   557.0   232.0( 50%)    301       301S    217.23     22     303
   3   304    226  1100P   249*     135.60     45.53     8.18    33.80    42.06   669.9    90.5( 40%)     27         79    132.85     20     304
   3   305    112   304S   249*      67.20     22.76     4.05    16.79    20.84   669.9    45.0( 40%)    304       304S     65.84     20     305
   3   306     56   304S   249*      33.60     11.38     2.03     8.40    10.42   669.9    22.5( 40%)    304       304S     32.92     20     306
   3   307   1358  2150P   105*     240.37     28.40     1.54    20.43    21.98    50.3   280.9( 21%)     14         23     90.75     83     307
   3   308    108   307S   105*      19.12      2.41      .24     1.63     1.87    62.3    44.1( 41%)    307       307S      7.81     83     308
   3   309    854  2150P    68      256.20     10.92     3.28      .33     3.60    15.2   502.5( 59%)     20         39     44.34     83     309
   3   310     96   309S    68       28.80      1.25      .37      .04      .40    15.2    56.5( 59%)    309       309S      4.93     83     310

   3 :         3684   MAX = 249*    1045.00    227.06    37.97   159.74   197.71   193.2  1354.5( 37%)                     680.06 PI =   148.9

                                                  <SYSTEM WIDE TOTALS INCLUDING ALL LINKS>.
   TOTAL       TOTAL      TOTAL       TOTAL       TOTAL     AVERAGE       TOTAL        TOTAL
  DISTANCE     TRAVEL    UNIFORM     RANDOM       DELAY      DELAY       UNIFORM        FUEL     OPERATING PERFORMANCE   SPEED
  TRAVELED      TIME      DELAY       DELAY                               STOPS        CONSUM       COST       INDEX
 (VEH-KM/H)  (VEH-H/H)  (VEH-H/H)  (VEH-H/H)   (VEH-H/H)  (SEC/VEH)    (VEH/H-%)      (LI/H)                              (KM/H)

  3016.01      556.21     104.12     346.90      451.02     175.00    4672.9( 55%)   1643.11     4129.30     (244.82)       5.02 <TOTALS>
<ROUTE SUMMARY REPORT>     THE TSD ORIENTATION DOWNBOUND ON THE PHOE IS WESTBOUND
 NODE LINK   FLOW    SAT.  DEGREE   TOTAL       TOTAL    -------- DELAY --------  AVERAGE    UNIFORM    MAX BACK   QUEUE      FUEL   PHASE   LINK
  NO.  NO.          FLOW   OF SAT   TRAVEL      TIME     UNIFORM  RANDOM   TOTAL   DELAY      STOPS     OF QUEUE CAPACITY   CONSUM  LENGTH   NO.
            (VEH/H)(VEH/H)  (%)   (VEH-KM/H)(VEH-H/H)        (VEH-H/H)          (SEC/VEH) (VEH/H;%)  (VEH/LK) (VEH/LK)   (LI/H)  (SEC)

   1   107    844  1950P   161*     337.60    105.12    15.61    79.86    95.47   407.2   525.7( 62%)     55  >      530    308.46     48     107
   2   204    884  2075     71      376.58     13.14     2.22      .43     2.65    10.8   211.2( 24%)      8         56     51.72     77     204
   3   307   1358  2150P   105*     240.37     28.40     1.54    20.43    21.98    50.3   280.9( 21%)     14         23     90.75     83     307
 DOWN   :      3086   MAX = 161*     954.55    146.66    19.37   100.73   120.10   140.1  1017.9( 35%)                     450.90 PI =    91.1

   1   110    540  2250P   100*     230.04     24.72     5.96    12.34    18.30   122.0   426.0( 79%)     37         56     81.26     40     110
   2   206    558  2215     98*      90.77     15.21     7.86     4.64    12.50    60.7   524.7( 94%)     18         23     51.86     34     206
   3   309    854  2150P    68      256.20     10.92     3.28      .33     3.60    15.2   502.5( 59%)     20         39     44.34     83     309
 UP     :      1952   MAX = 108*     585.01     50.84    17.09    17.51    34.40    65.4  1453.5( 74%)                     177.46 PI =    29.6
                                                      <ROUTE TOTALS>
   TOTAL       TOTAL      TOTAL       TOTAL       TOTAL     AVERAGE       TOTAL        TOTAL
  DISTANCE     TRAVEL    UNIFORM     RANDOM       DELAY      DELAY       UNIFORM        FUEL     OPERATING PERFORMANCE   SPEED
  TRAVELED      TIME      DELAY       DELAY                               STOPS        CONSUM       COST       INDEX
 (VEH-KM/H)  (VEH-H/H)  (VEH-H/H)  (VEH-H/H)   (VEH-H/H)  (SEC/VEH)    (VEH/H-%)      (LI/H)                              (KM/H)

  1539.56      197.50      36.46     118.04      154.50     110.40    2471.1( 49%)    628.57      506.41      120.68        7.80 <TOTALS>
```

Fig 4.19 Optimal solution using phase sequence 19,5,6

(Check Iteration)

ITERATION : 6 (to test the algorithm)

Input Cycle Length: 105 seconds

Resulting Sequence: 3,5,6

Resulting PI Value: 345.23

Best Cycle Length Over Range: 115 seconds

Resulting PI Value: 343.91 (greater than iteration 3)

Reference: Table 4.8, Fig 4.20, Fig 4.21

Table 4.8 Resulting PI's for cycle length of 105 sec

Phase Sequence	Node 1	Node 2	Node 3	System Wide
1,1,1	164.7	27.5	155.2	347.37
2,2,2	163.5	31.8	167.3	362.59
3,3,3	162.3	34.2	154.0	350.50
4,4,4	163.2	29.9	157.4	350.55
5,5,5	166.5	27.1	153.7	347.37
6,6,6	162.5	27.3	150.8	340.63
7,6,1	167.6	27.9	158.1	353.57
8,1,2	165.5	27.4	170.1	362.94
9,2,3	167.0	32.2	151.7	350.86
10,3,4	166.5	31.5	157.9	355.81
11,4,5	163.8	30.1	155.9	349.83
12,5,6	164.7	29.7	153.0	347.43
13,6,1	171.0	27.1	154.9	353.05
14,5,2	167.5	27.8	167.8	363.08
15,4,3	165.5	29.0	153.9	348.42
16,3,4	165.6	32.1	160.7	358.40
17,2,5	164.4	32.1	157.3	353.68
18,6,1	163.4	27.3	155.5	346.20
19,5,2	162.5	30.7	167.0	360.17
20,1,6	164.3	28.0	149.8	342.12
21,2,1	162.5	32.3	156.9	351.76
22,3,2	162.6	32.6	168.0	363.15
23,4,3	165.3	28.8	153.6	347.67
24,5,4	166.4	27.7	158.5	352.53

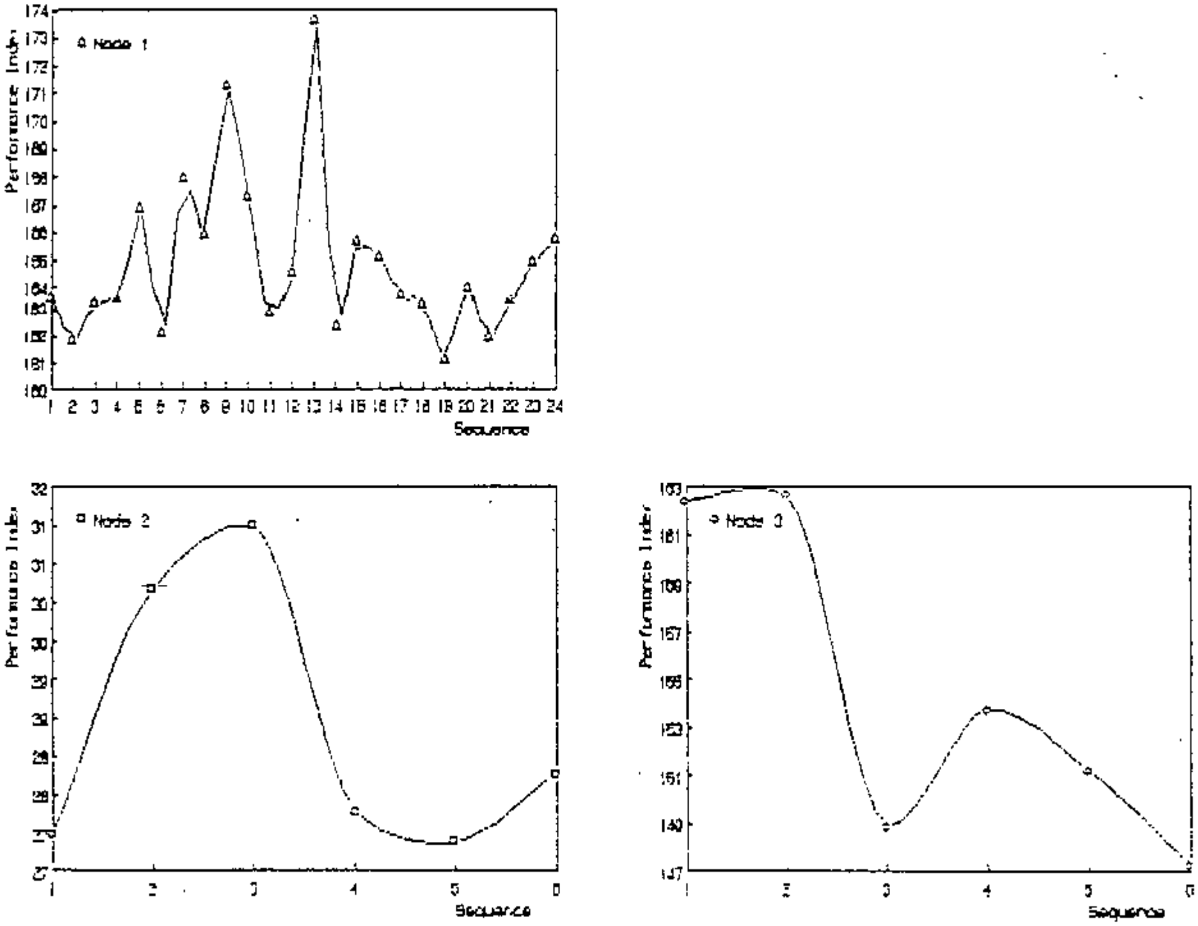
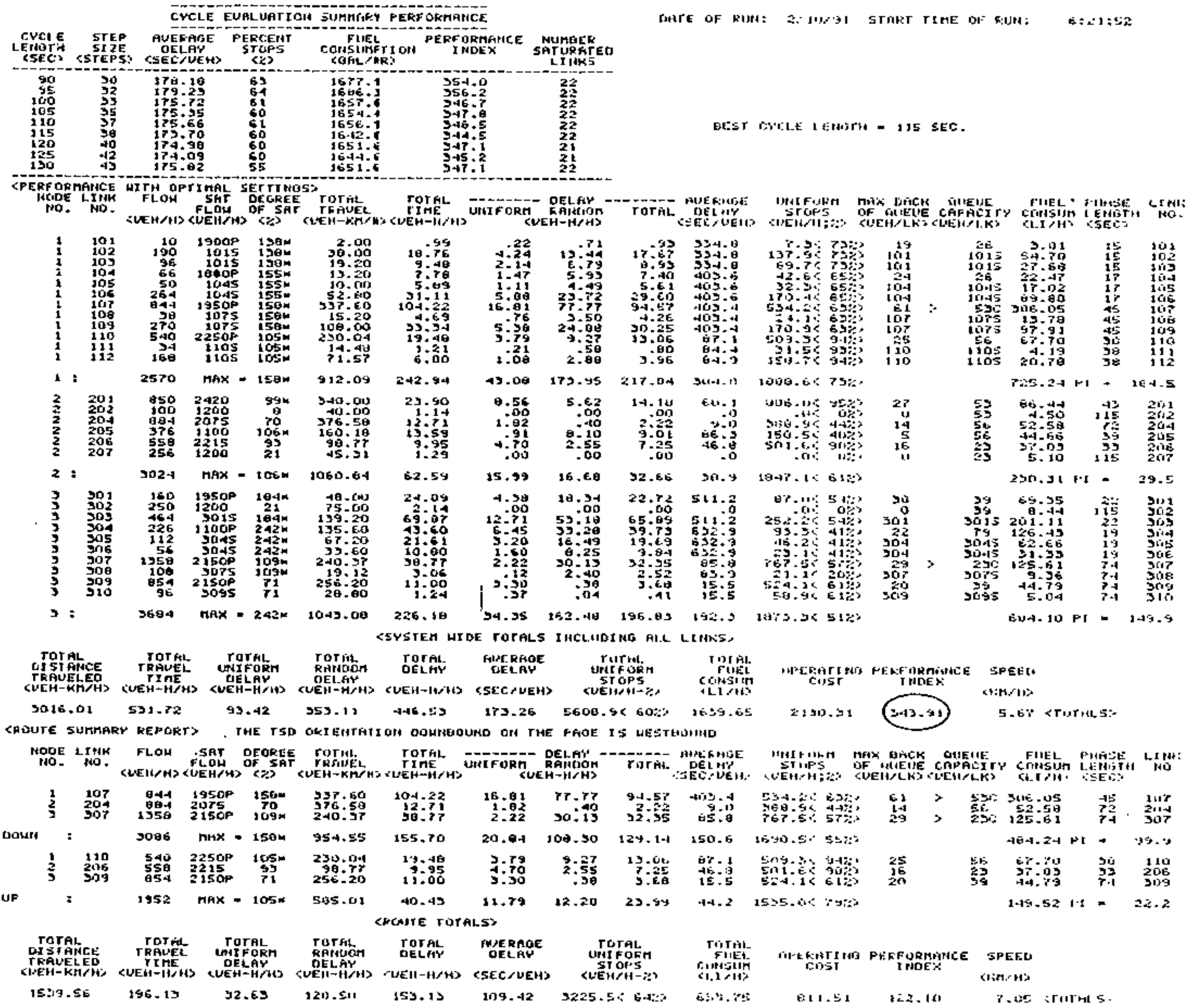


Fig 4.20 PI values versu' phase sequences for each node (105 sec)

Phase Sequence	System Wide PI
3,5,6	345.23



```
               ---------------------------------------
               CYCLE EVALUATION SUMMARY PERFORMANCE                          DATE OF RUN:  2/10/91   START TIME OF RUN:    6:21:52
               ---------------------------------------
 CYCLE    STEP    AVERAGE   PERCENT      FUEL        PERFORMANCE  NUMBER
LENGTH    SIZE     DELAY     STOPS    CONSUMPTION       INDEX    SATURATED
 <SEC>  <STEPS>  <SEC/VEH>    <%>       <GAL/HR>                   LINKS
-------------------------------------------------------------------------
   90      30     178.10      63        1677.1          354.0        22
   95      32     179.23      64        1666.1          356.2        22
  100      33     175.72      61        1657.6          346.7        22
  105      35     175.35      60        1654.4          347.8        22
  110      37     175.66      61        1656.1          346.5        22
  115      38     173.70      60        1642.6          344.5        22                BEST CYCLE LENGTH = 115 SEC.
  120      40     174.98      60        1651.6          347.1        21
  125      42     174.09      60        1644.6          345.2        21
  130      43     175.02      55        1651.6          347.1        22
-------------------------------------------------------------------------
<PERFORMANCE WITH OPTIMAL SETTINGS>
   NODE LINK    FLOW    SAT   DEGREE    TOTAL       TOTAL   --------- DELAY ---------  AVERAGE     UNIFORM    MAX BACK   QUEUE      FUEL   PHASE   LINK
    NO.  NO.            FLOW  OF SAT    TRAVEL      TIME    UNIFORM  RANDOM    TOTAL    DELAY       STOPS    OF QUEUE  CAPACITY   CONSUM  LENGTH   NO.
              <VEH/H> <VEH/H>  <%>   <VEH-KM/H> <VEH-H/H>      <VEH-H/H>             <SEC/VEH>  <VEH/H;%>  <VEH/LK> <VEH/LK>    <LI/H>  <SEC>

     1   101      10  1900P   158*      2.00       .99      .22      .71      .93    334.8     7.5< 73%>     19          26      3.01     15    101
     1   102     190   1015   158*     38.00     18.76     4.24    13.44    17.67    334.8   137.9< 73%>    101        1015     54.70     15    102
     1   103      96   1015   158*     19.20      9.48     2.14     6.79     8.93    334.8    69.7< 73%>    101        1015     27.68     15    103
     1   104      66  1800P   155*     13.20      7.78     1.47     5.93     7.40    405.6    42.6< 65%>     24          26     22.47     17    104
     1   105      50   1045   155*     10.00      5.69     1.11     4.49     5.61    405.6    32.5< 65%>    104        1045     17.02     17    105
     1   106     264   1045   155*     52.80     31.11     5.88    23.72    29.60    405.6   170.4< 65%>    104        1045     69.80     17    106
     1   107     844  1950P   158*    537.60    104.22    16.81    77.77    94.57    403.4   534.2< 63%>     61   >     550    306.05     45    107
     1   108      38   1075   158*     15.20      4.69      .76     3.50     4.26    403.4    24.1< 63%>    107        1075     13.78     45    108
     1   109     270   1075   158*    108.00     33.34     5.38    24.08    30.25    403.4   170.9< 63%>    107        1075     97.91     45    109
     1   110     540  2250P   105*    230.04     19.48     3.79     9.27    13.06     87.1   509.3< 94%>     25          56     67.70     30    110
     1   111      34   1105   105*     14.48      1.21      .21      .58      .80     84.4    31.5< 93%>    110        1105      4.19     38    111
     1   112     168   1105   105*     71.57      6.00     1.08     2.88     3.96     64.9   159.7< 94%>    110        1105     20.78     38    112

     1 :        2570    MAX = 158*    912.09    242.94    43.08   173.95   217.04    304.0  1008.6< 75%>                         725.24 PI =  164.5

     2   201     850   2420    99*    340.00     23.90     8.56     5.62    14.18     60.1   808.0< 95%>     27          53     86.44     43    201
     2   202     100   1200     0      40.00      1.14      .00      .00      .00       .0      .4<  0%>      0          53      4.50    115    202
     2   204     884   2075    70     376.58     12.71     1.82      .40     2.22      9.0   388.9< 44%>     14          56     52.58     72    204
     2   205     376   1100   106*    160.18     13.59      .91     8.10     9.01     86.3   150.5< 40%>      5          56     44.66     39    205
     2   206     558   2215    93      98.77      9.95     4.70     2.55     7.25     46.8   501.6< 90%>     16          23     37.03     33    206
     2   207     256   1200    21      45.31      1.29      .00      .00      .00       .0      .0<  0%>      0          23      5.10    115    207

     2 :        3024    MAX = 106*   1060.64     62.59    15.99    16.68    32.66     38.9  1847.1< 61%>                         250.31 PI =   29.5

     3   301     160  1950P   184*     48.00     24.09     4.38    18.34    22.72    511.2    87.0< 54%>     38          39     65.55     22    301
     3   302     250   1200    21      75.00      2.14      .00      .00      .00       .0      .0<  0%>      0          39      8.44    115    302
     3   303     464   3015   184*    139.20     69.07    12.71    53.18    65.89    511.2   252.2< 54%>    301        3015    201.11     22    303
     3   304     226  1100P   242*    135.60     43.60     6.45    33.28    39.73    632.9    93.3< 41%>     22          79    126.45     19    304
     3   305     112   3045   242*     67.20     21.61     3.20    16.49    19.69    632.9    46.2< 41%>    304        3045     62.66     19    305
     3   306      56   3045   242*     33.60     10.00     1.60     8.25     9.84    632.9    23.1< 41%>    304        3045     31.33     19    306
     3   307    1358  2150P   109*    240.37     38.77     2.22    30.13    32.35     85.8   767.5< 57%>     29   >     250    125.61     74    307
     3   308     108   3075   109*     19.12      3.06      .12     2.40     2.52     83.9    21.1< 20%>    307        3075      9.36     74    308
     3   309     854  2150P    71     256.20     11.00     3.30      .38     3.68     15.5   524.1< 61%>     20          39     44.79     74    309
     3   310      96   3095    71      28.80      1.24      .37      .04      .41     15.5    58.9< 61%>    309        3095      5.04     74    310

     3 :        3684    MAX = 242*   1043.08    226.18    34.35   162.48   196.83    192.3  1873.3< 51%>                         604.10 PI =  149.9

                                                <SYSTEM WIDE TOTALS INCLUDING ALL LINKS>

    TOTAL         TOTAL      TOTAL       TOTAL       TOTAL     AVERAGE        TOTAL         TOTAL
  DISTANCE       TRAVEL     UNIFORM      RANDOM      DELAY      DELAY        UNIFORM         FUEL      OPERATING PERFORMANCE  SPEED
  TRAVELED        TIME       DELAY       DELAY                               STOPS         CONSUM        COST       INDEX
 <VEH-KM/H>   <VEH-H/H>   <VEH-H/H>   <VEH-H/H>   <VEH-H/H>  <SEC/VEH>     <VEH/H-%>      <LI/H>                              <KM/H>

   3016.01       531.72      93.42      353.11      446.53     173.26     5608.9< 60%>    1659.65      2130.51     343.91        5.67 <TOTALS>
<ROUTE SUMMARY REPORT>   . THE TSD ORIENTATION DOWNBOUND ON THE PAGE IS WESTBOUND
   NODE LINK    FLOW   .SAT   DEGREE    TOTAL       TOTAL   --------- DELAY ---------  AVERAGE     UNIFORM    MAX BACK   QUEUE      FUEL   PHASE   LINK
    NO.  NO.            FLOW  OF SAT    TRAVEL      TIME    UNIFORM  RANDOM    TOTAL    DELAY       STOPS    OF QUEUE  CAPACITY   CONSUM  LENGTH   NO
              <VEH/H> <VEH/H>  <%>   <VEH-KM/H> <VEH-H/H>      <VEH-H/H>             <SEC/VEH>  <VEH/H;%>  <VEH/LK> <VEH/LK>    <LI/H>  <SEC>

     1   107     844  1950P   158*    537.60    104.22    16.81    77.77    94.57    403.4   534.2< 63%>     61   >     550    306.05     45    107
     2   204     884   2075    70     376.58     12.71     1.82      .40     2.22      9.0   388.9< 44%>     14          56     52.58     72    204
     3   307    1358  2150P   109*    240.37     38.77     2.22    30.13    32.35     85.8   767.5< 57%>     29   >     250    125.61     74    307
 DOWN    :      3086    MAX = 158*    954.55    155.70    20.04   108.30   129.14    150.6  1690.5< 55%>                         484.24 PI =   99.9

     1   110     540  2250P   105*    230.04     19.48     3.79     9.27    13.06     87.1   509.3< 94%>     25          56     67.70     30    110
     2   206     558   2215    93      98.77      9.95     4.70     2.55     7.25     46.8   501.6< 90%>     16          23     37.03     33    206
     3   309     854  2150P    71     256.20     11.00     3.30      .38     3.68     15.5   524.1< 61%>     20          39     44.79     74    309

 UP      :      1952    MAX = 105*    585.01     40.45    11.79    12.20    23.99     44.2  1555.0< 79%>                         149.52 PI =   22.2

                                                <ROUTE TOTALS>

    TOTAL         TOTAL      TOTAL       TOTAL       TOTAL     AVERAGE        TOTAL         TOTAL
  DISTANCE       TRAVEL     UNIFORM      RANDOM      DELAY      DELAY        UNIFORM         FUEL      OPERATING PERFORMANCE  SPEED
  TRAVELED        TIME       DELAY       DELAY                               STOPS         CONSUM        COST       INDEX
 <VEH-KM/H>   <VEH-H/H>   <VEH-H/H>   <VEH-H/H>   <VEH-H/H>  <SEC/VEH>     <VEH/H-%>      <LI/H>                              <KM/H>

   1539.56       196.15      32.63      120.50      153.13     109.42     3225.5< 64%>     655.78       811.51     122.10        7.05 <TOTALS>
```

Fig 4.21 Optimal solution using phase sequence 3,5,6

4.4.2 Results of Research:

Results of algorithm iterations are shown in Table 4.9. This table summarizes different steps of the algorithm that has been developed in order to get a good solution.

Table 4.9 Summary of iterations done to reach solution

Iteration	Input Cycle Length	Resulting		Output Cycle Length	PI
		PI	Sequence		
1	100	346.93	19,5,1	120	349.14
2	120	341.53	6,4,3	125	342.84
3	125	339.53	2,1,3	125	337.22
Ckeck, 4	115	339.35	19,1,3	125	337.84
Ckeck, 5	110	343.57	19,5,6	125	344.82
Ckeck, 6	105	345.23	3,5,6	115	343.91

Table 4.9 is reproduced in a plot-form as shown in Fig 4.22. The convergance of algorithm was at 125 seconds cycle length. At that length, the resulting performance index PI was the minimum among the other values. Also, the resulting cycle length was the same as the input cycle length (125 seconds).

A summary of results of this research are shown in Table 4.10. The summary shows all the PI values sequences that had been found and tested. This table is plotted as shown in Fig 4.23. The curve that represents phase sequence 2,1,3 has the least PI values among all other phase sequences tested.

Improvement in the system has been calculated considering different parameters of the system as performance index, fuel

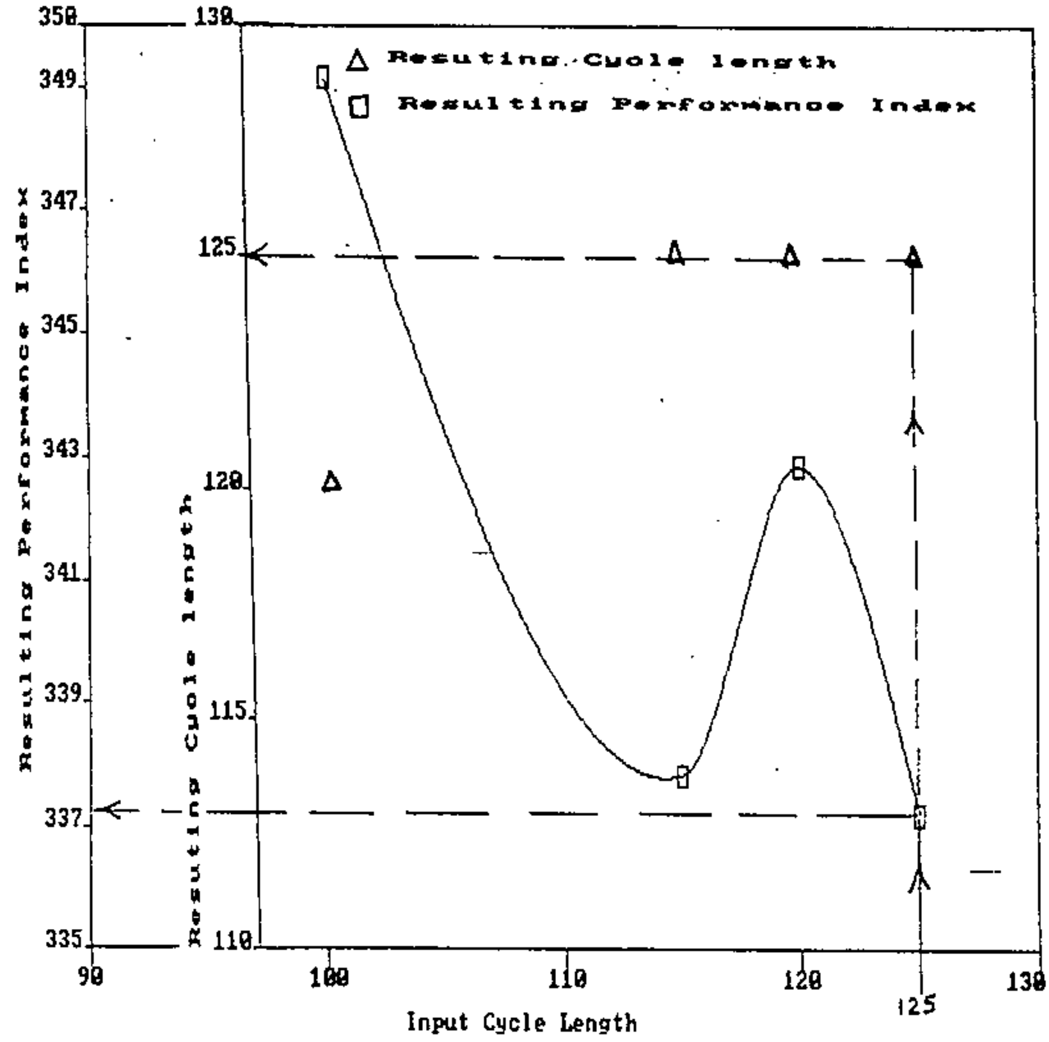


Fig 4.22 Summary of iterations done to reach solution

consumption, total delay, average delay, operating cost, and total travel time. The comparison was between the installed setting and phase sequence, and the recommended solution that was found (phase sequence 2,1,3). This comparison and the improvement are shown in Table 4.11.

Table 4.10 Summary of Results (Performance Index Values)

Column Number			1	2	3	4	5	6	7	
Sequence	Run Type	Cycle Length	Node			System Wide	Route			Remarks
			1	2	3		Down	Up	Total	*
1,1,1	Sim	100	176.2	36	175.6	387.7	170	48.9	218.82	Installed S.T.P & Phase Sequence
1,1,1	Opt	100	164.6	28.2	156	348.83	126	29.2	155.27	Installed S.T.P & Phase Sequence
19,5,1	Opt	120	161.4	33.2	154.6	349.14	122.7	27.5	150.25	Range 90-130 sec
6,4,3	Opt	125	164.6	32.1	146.2	342.84	99.5	38.3	137.84	Range 90-130 sec
19,1,3	Opt	125	163	27.9	147	337.84	102.4	22.7	125.09	Range 90-130 sec
2,1,3	Opt	125	162.6	28.7	145.9	337.22	92.2	22.8	114.9	Range 90-130 sec

* S.T.P Signal Timing Plan

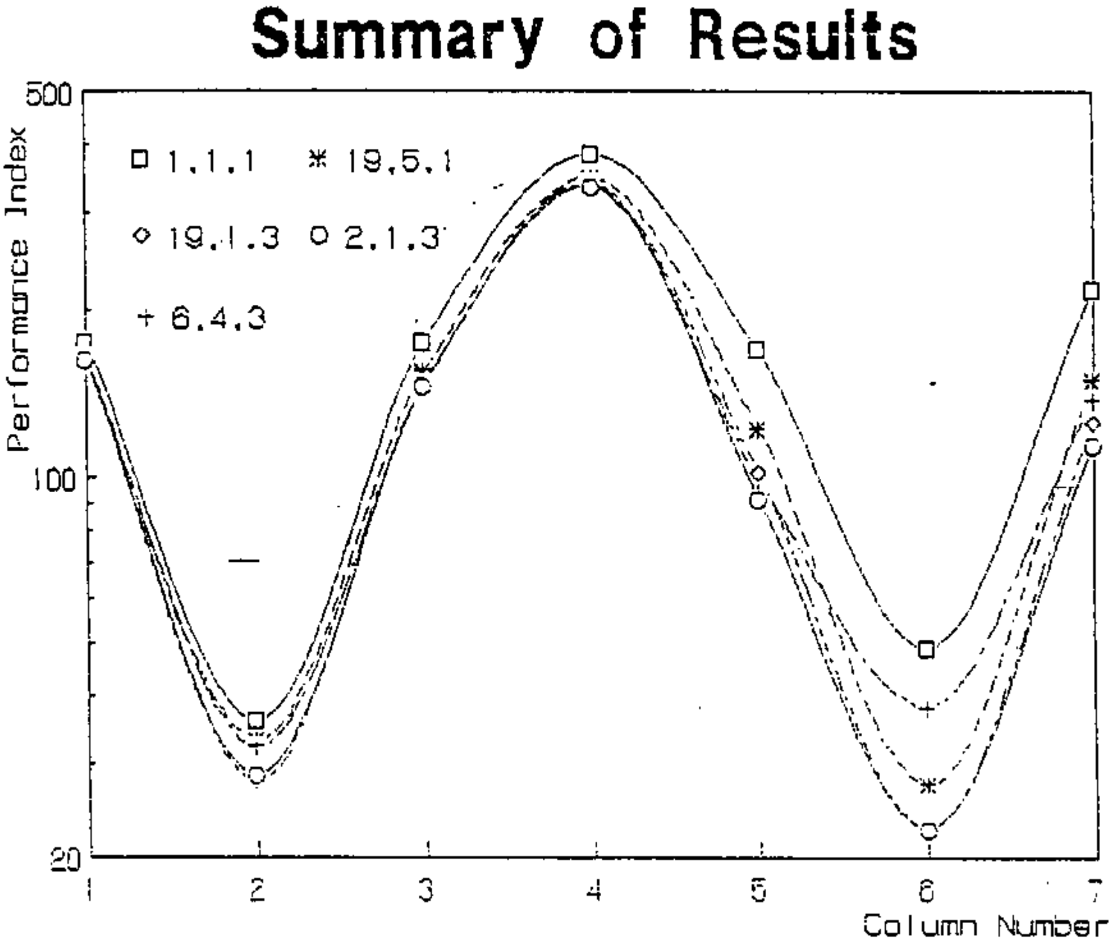


Fig 4.23 Plot for every sequence developed by algorithm

Table 4.11 Improvement in System (Prince Shaker Street)

Parameter			Installed Setting	Recomm. Solution	% Improv.
Performance Index	Node	1	176.2	162.6	7.72
		2	36	28.7	20.28
		3	175.6	145.9	16.91
	S.W.		387.7	337.22	13.02
	Route	Up	170	92.2	45.76
		Down	48.9	22.8	53.37
		Tot.	218.82	114.9	47.49
Fuel Consumption (Li/Hr)	Node	1	769.4	718.14	6.66
		2	254.89	227.41	10.78
		3	781.13	668.8	14.38
	S.W.		1805.42	1614.34	10.58
	Route	Up	749.55	455.01	39.30
		Down	250.31	151.5	39.48
		Tot.	999.86	779.62	22.03
Total Delay (Veh-H/H)	S.W.		504.87	439.97	12.85
	Route		285.39	145.77	48.92
Average Delay (Sec/H)	S.W		195.9	170.71	12.86
	Route		203.93	104.17	48.92
Operating Cost	S.W		2335.82	2095.22	10.30
	Route		1260.32	779.62	38.14
Total Travel (Veh-H/H)	S.W		590.06	525.15	11.00
	Route		328.4	188.78	42.52

4.5 Conclusions:

In the matter of time needed to reach the solution, i.e. the optimum cycle length, it can be seen clearly from Table 4.9 that the best performance index PI was reached after three iterations. The number of computer runs per iteration was 24 plus one run to make a cycle evaluation. This makes the total number of runs needed to reach the solution equal to 75. The check iteration also needed 25 computer runs. This adds up to a total of 100 computer runs needed for the solution.

On the other hand, in order to find the best solution using the method described in TRANSYT, the number of runs needed are 864 plus one cycle evaluation, which adds up to a total of 865 computer runs.

As it was expected, the developed algorithm shows a rapid convergance. In the case of Prince Shaker Street we dealt with, the convergance took about 12% of the time needed for using the method of TRANSYT-7F (100 runs using algorithm versus 865 runs using method of TRANSYT-7F).

In the matter of improvement in the system, it can be seen clearly from the summary of results (Table 4.10) that the best phase sequence (2,1,3) that resulted has the minimum system and route performance index (PI). Also, and as shown in Table(4.11), the recommended solution has improved the system by 6.6% in fuel consumption at node 1 and 14.4% at node 3. Furthermore, the system has been improved in the total and in the average delay by about 49%. Also, the total travel has been improved by a very good percentage in the sense that it has increased by about 43% on the main street. Based on these results, the developed algorithm has been shown to be a good tool to be applied in order to reach a good solution with a high confidence level.

Concerning the best cycle length found, there are some factors that affect the selection of cycle length greater than 120 seconds. Among these factors are the existance of more than four approaches for the intersection, more than four phases for the timing plan, and high traffic volumes which cause high congestion at the intersection. Because of these reasons, the author recommends the installation of 115 second cycle length since it ranked second in PI values (table 4.9).

Chapter Five

Summary and Recommendations for Future Research

5.1 Summary:

The objective of this thesis was to **Set an Effecient Signal Sequence and Timing for Interconnected Traffic Signals.** This problem was solved by developing an algorithm that was implemented on TRANSYT-7F. That algorithm had resulted in an optimal or near optimal solution with a high confidence level. The developed algorithm showed a very good time saving in the computer run time. In the case we dealt with, the reduction in time was about 80% when using a PC-AT (without math-coprocessor).

The recommended solution of the phase sequences and signal timing plans for the three intersections studied showed significant improvements. These improvements in the different parameters were summarized in Table 4.11.

Delay, which was the major parameter in the study that we attempted to minimize, had been reduced by about 48% in the main street. Also, fuel consumption was decreased by about 22% for the same route. Overall, the recommended solution has proved to introduce a significant improvement.

5.2 Recommendations for Future Research:

In coducting the research for this thesis, some ideas were contemplated but, due to time limitations, could not be tried. Among these are:

1) Left-turn movements are allowed at Wahbi Tamari (node 1)

and Flying Carpet (node 2) intersections. But, these movements are protected. In other words, they have separate phase. They can only move on the green arrow (they have their own right-of-way). A study could be conducted on the effect of unprotected left-turn movements, which has no exclusive right-of way and, must only rely on gaps in the opposing traffic to find how this solution can affect delay.

2) In this study, no constructional changes were assumed. In other words, for example, no approach widening was done. So, a study could be made in order to find the effect of approach widening on delay and other traffic parameters and, how this change could affect the behaviour of the flow of traffic.

References

1) Louis J. Pignataro, "**Traffic Engineering: theory and practice**", Prentice-Hall Inc., Englewood Cliffs, New Jersey, 1973.

2) R. J. Satter, "**Highway Traffic Analysis and Design**", Macmillan Education Ltd., Houndmills, Basingstore, Hampshire RG21 2XS and London, 2nd Edition, 1989.

3) Classroom Notes, **C.E. 774 Design and Operation of Traffic Facilities**, The Ohio State University, Wi. 1986.

4) Robert M. Shanteau, "**Using Cummulative Curves to Measure Saturation Flow and Lost Time**", ITE journal, Vol 58, No. 10, Oct. 1988.

5) I. G. Taylor, Margaret C. Bell and G. M. Geary, "**Queue Volume: a measure of congestion**", Traffic Engineering and Control, pp582 - 585, Nov. 1987.

6) Feng-Bor Lin, M. ASCE and Donald Cooke, "**Modeling of Queue Dissipation for Signal Control**", Journal of Transportation Engineering, Vol. 112, No. 6, pp593-609, Nov. 1986.

7) B. N. Srikar and B. Vinod, "**Performance Analysis and Capacity Planning of a Landing Gear Shop**", INTERFACES, Vol 19, No. 4, July-August 1989, pp. 52-60.

8) **TRANSYT-7F**, User's Manual, Rel 6, US Department of Transportation, FHWA, Washington, D.C., Oct 1988.

9) Edmond Chin-Ping Chang, Carroll . Messer, Rene U. Garza, "**Arterial Signal Timing Optimization Using PASSER II-87**", ITE Journal, Vol 58, No. 11, Nov 1988.

10) Blair G. marsden, Edmond Chin-Ping Chang, B. Ray Derr, "**The PASSER II-84 System: A Practical Signal Timing Tool**", ITE

Journal, Vol 57, No. 3, Mar 1987.

11) **GPSS/PC™**, Reference Manual, general purpose simulation, Minuteman Software, 1988.

12) Shui-Ying Wong, "**Application of TRANSYT-7F in China**", ITE Journal, Vol 58, No. 8, Aug 1988.

13) K. C. Kapur and L. R. Lamberson, "**Reliability in Engineering Design**", John Wiley and Sons, New York, 1977.

14) William W. Hines and Douglas C. Montgomery, "**Probability and Statistics in Engineering and Management Science**", 2nd Edition John Wiley and Sons, New York, 1980.

15) Thomas J. Schriber, "**Simulation Using GPSS**", John Wiley & Sons, 1974.

16) **Traffic Engineering Handbook**, 3rd edition, 1965.

17) **Transportation Glossary**, AASHTO publication, 1983.

18) Robert W. Stokes, "**Comparison of Saturation Flow Rates at Signalized Intersections**", ITE journal, Vol 58, No. 11, Nov. 1988.

19) Hamdy A. Taha, "**Operations Research, An Introduction**", Macmillan Publishing Company, 4th edition, 1987.

20) **Highway Capacity Manual**, Special Report 209, Transportation Research Board, National Research Council, Washington D.C., 1985.

Appendices

Bound: The direction at which the traffic is comming from.

Capacity: Maximum number of vehicles that can pass over a given section of a lane or roadway during a given time period, under prevailing roadway and traffic conditions.

Clearance Interval: The interval from the end of the yellow period associated with one phase to the beginning of a conflicting phase.

Cycle Length: The time required for one complete sequence of signal indications.

Degree of Saturation: The ratio of the flow to the maximum possible flow under the given settings of the signals.

Delay: Time lost while traffic is impeded by some element over which the driver has no control, such as traffic signal.

External Link: A link entering the network, having no upstream input in the network.

Flow: The volume of traffic, normally in vehicles per hour (vph).

Fuel Consumption: The estimate of the amount of fuel consumed by all vehicles in a network in liters.

Link: The unidirectional roadway between two signalized locations.

Lost Time: The unproductive time during the cycle for moving vehicles.

Node: The representation of an intersection of two or more streets.

Offset: In a signal system, the time difference in seconds between system time base and the start of a specified interval.

Peak Hour Factor (PHF): The ratio of vehicles entering the intersection during the peak hour to four times the number of vehicles entering during the peak 15-minutes period.

Peak Period: The period of day when traffic demands are typically the highest.

Performance Index: The optimization objective function of TRANSYT-7F, a linear combination of delay (veh-hr) and stops (veh-sec) or total operating cost.

Phase: A portion of a signal cycle during which the right-of-way is made to given traffic movements.

Phase Sequence: The order in which the traffic movements are given the right-of-way in a signal cycle.

Queue Length: The number of vehicles which are stopped or moving in a line where the movement of each vehicle is constrained by that of the lead vehicle.

Saturation Flow: The flow in vehicles per hour which would be obtained if there was a continueous queue of vehicles, and they were given a 100 percent green time.

Traffic Volume: The actual passage of traffic past a particular point of a roadway during a given period of time. Measured in vehicles per hour.

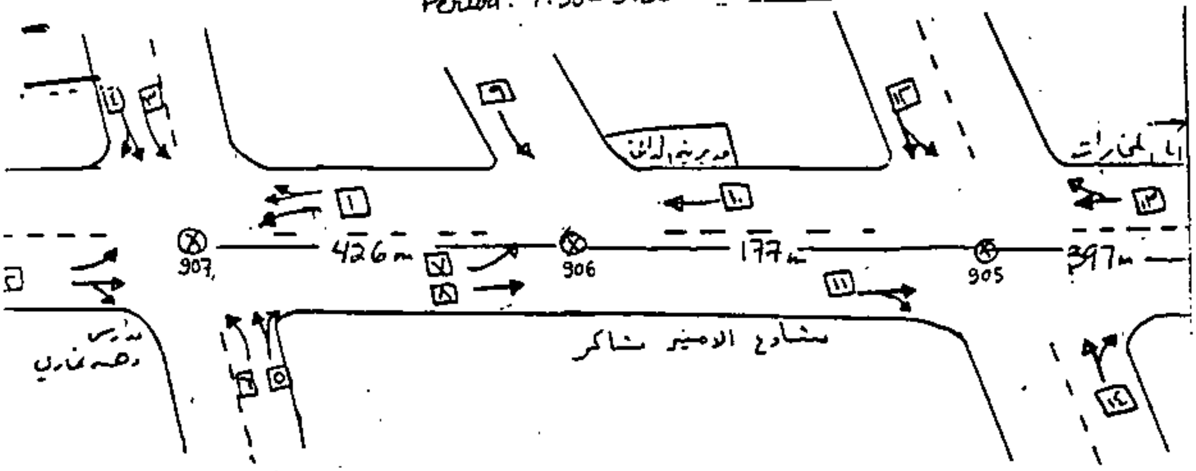
APPENDIX B

Webster's Formula

(Program calculates delay)

```
10 '*********************************************************
30 'This program calculates the DELAY  using WEBSTER's method
50 'that was represented in Road Research Technical Paper 39
70 'This method calculates the Average Delay per Vehicle on a
90 'particular intersection arm.
110 '*********************************************************
130 INPUT "Lambda =",L
150 INPUT "Degree of Saturation 'x' =",X
170 INPUT "Flow 'q' =",Q
190 INPUT "Cycle Length 'c' =",CY
210 MX = 1-X
230 MLAM = 1-L
250 DEN = (1-L*X)
270 A = (CY*(MLAM^2))/(2*DEN)
290 B = (X^2)/(2*Q*MX)
310 TL = 2+5*L
330 CQ = CY/Q^2
350 C = .65*(CQ^.3333)*(X^TL)
370 DELAY = A+B-C
390 PRINT "A= ",A: PRINT "B= ",B: PRINT "C= ",C
410 PRINT "Delay =",DELAY
```

TRAFFIC COUNTS: Period: 7:30-9:30



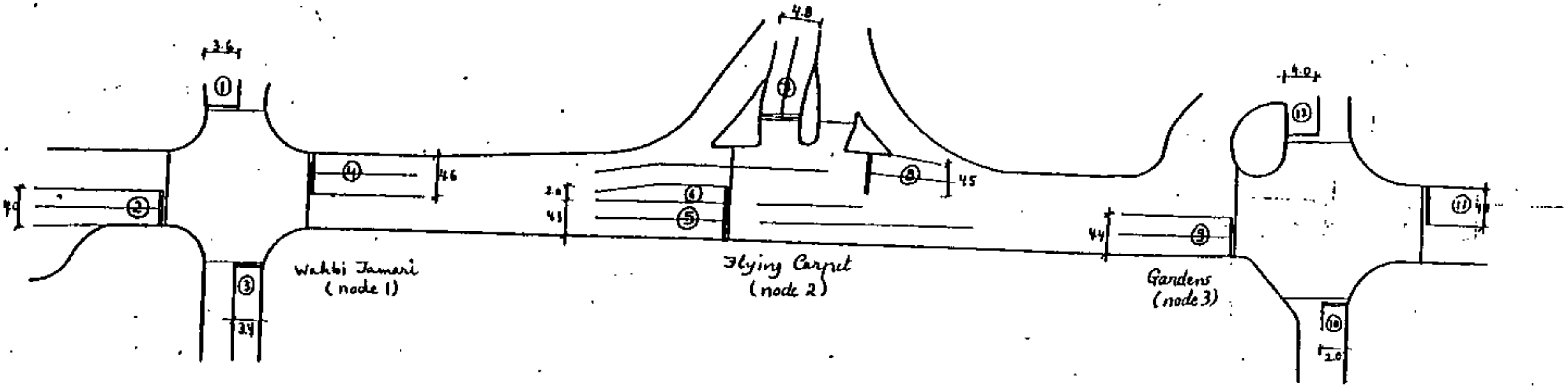
MOVEMENT / TIME PERIOD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
7.00 - 7.15									—						
7.15 - 7.30															
7.30 - 7.45	120/40	233/60	27	78	23	62	91	220	203	146	343	114	201	80	
7.45 - 8.00	116/46	206/125	26	71	28	64	97	222	212	133	378	172	236	117	
8.00 - 8.15	171/38	197/84	22	56	30	68	83	204	213	100	355	140	239	62	
8.15 - 8.30	99/7	211/75	18	47	15	31	89	208	191	96	326	91	201	48	
8.30 - 8.45	129/12	198/55	16	32	14	15	85	168	164	128	325	88	155	40	
8.45 - 9.00	149/15	180/45	11	44	13	16	42	101	158	149	253	83	169	35	
9.00 - 9.15	145/13	193/70	10	21	9	10	66	130	119	96	282	93	203	33	
9.15 - 9.30	184/10	192/52	15	27	17	19	71	166	120	101	226	79	178	36	
9.30 - 9.45															
9.45 - 10.00															
Sub total															
TOTAL															

Intersection : 905, 906, 907

Date : 29/5/1989

Day : Tuesday

Weather Conditions : Sunny


3.6
①
40
②
③
34
④
46
Wahbi Jamari
(node 1)
4.8
⑦
2.0
43
⑥
⑤
⑧
45
Flying Carpet
(node 2)
44
⑨
Gardens
(node 3)
4.0
⑫
⑪
40
⑩
2.0

Wahbi Tamari Intersection

PERIOD	1	2	3	4
7:30 - 7:45	100	295	85	160
7:45 - 8:00	97	331	92	162
8:00 - 8:15	78	281	98	209
8:15 - 8:30	65	286	46	106
8:30 - 8:45	48	253	29	141
8:45 - 9:00	55	225	29	164
9:00 - 9:15	31	263	19	158
9:15 - 9:30	42	242	36	196
TOTALS	516	2176	434	1296

Flying Carpet Intersection

PERIOD	5	6	7	8
7:30 - 7:45	220	91	203	146
7:45 - 8:00	222	97	212	133
8:00 - 8:15	204	83	213	100
8:15 - 8:30	208	89	191	96
8:30 - 8:45	168	85	184	128
8:45 - 9:00	101	42	158	149
9:00 - 9:15	130	66	119	96
9:15 - 9:30	166	71	120	101
TOTALS	1419	624	1400	949

Gardens Intersection

PERIOD	9	10	11	12
7:30 - 7:45	343	80	201	114
7:45 - 8:00	378	117	236	172
8:00 - 8:15	355	62	239	140
8:15 - 8:30	326	48	201	91
8:30 - 8:45	325	40	155	88
8:45 - 9:00	253	35	169	83
9:00 - 9:15	282	33	203	93
9:15 - 9:30	226	36	178	79
TOTALS	2488	451	1582	860

APPENDIX D

Solution of Wahbi Tamari Intersection
Using Webster's Equation

Wahbi Tamari's Intersection

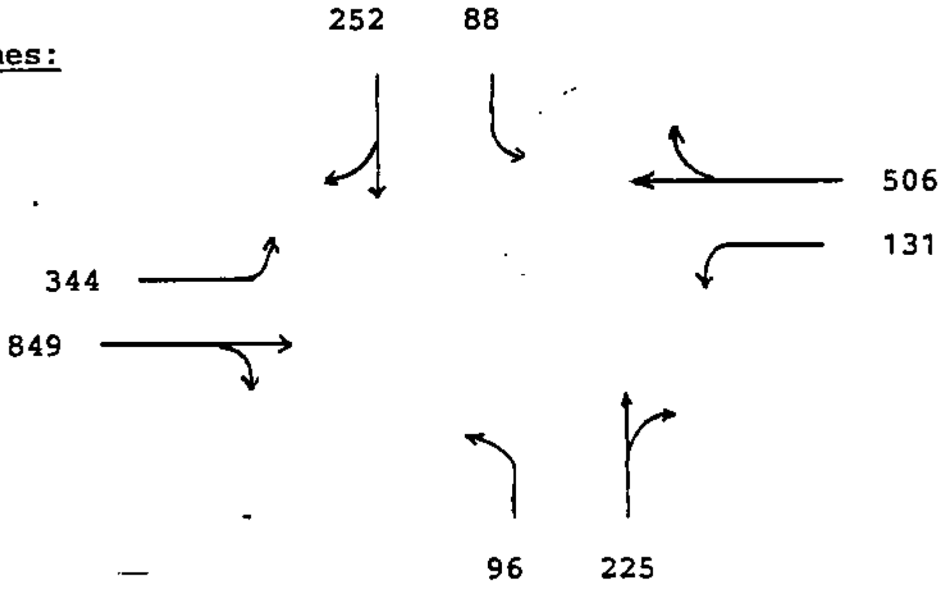
Traffic flow data for each approach in the a.m. peak

TIME	N B		S B		E B		W B		Tot.	Cum Total
	↳	↲↓	↰	↑↱	↙	←↑	↗	→↓		
7:30 - 7:45	22	78	23	62	40	120	60	235	640	2491
7:45 - 8:00	26	71	28	64	46	116	125	206	682	2322
8:00 - 8:15	22	56	30	68	38	171	84	197	666	2113
8:15 - 8:30	18	47	15	31	7	99	75	211	503	1918
8:30 - 8:45	16	32	14	15	12	129	55	198	471	1931
8:45 - 9:00	11	49	13	16	15	149	45	180	473	
9:00 - 9:15	10	21	9	10	13	145	70	193	471	
9:15 - 9:30	15	27	17	19	10	186	50	192	516	

As it can be seen from table, the maximum cummulative volume corresponds to the period from 7:30-8:30. Though, this period will be considered in computations.

TIME	N B		S B		E B		W B		TOTAL
	↳	↲↓	↰	↑↱	↙	←↑	↗	→↓	
7:30 - 7:45	22	78	23	62	40	120	60	235	640
7:45 - 8:00	26	71	28	64	46	116	125	206	682
8:00 - 8:15	22	56	30	68	38	171	84	197	666
8:15 - 8:30	18	47	15	31	7	99	75	211	503
TOTAL	88	252	96	225	131	506	344	849	2491

Volumes:

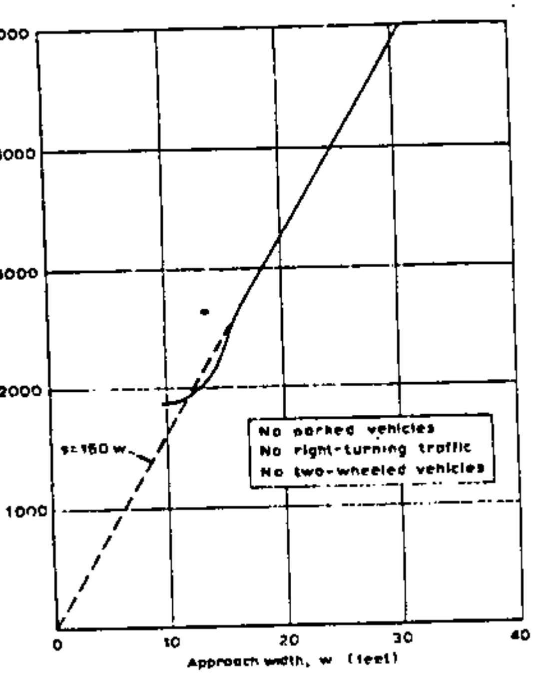


Approach	Saturation Flow
East Bound	2250
West Bound	1950
North Bound	1900
South Bound	1880

$$PHF = \frac{\text{Total flow in 1 Hr}}{4 \text{ (Max flow of 15 min)}} = \frac{2491}{4*682}$$

$$= 0.913$$

VOLUME ADJUSTMENT WORKSHEET										
① Appr.	② Mvt.	③ Mvt. Volume (vph)	④ Peak Hour Factor PHF	⑤ Flow Rate v_p (vph) ③ ÷ ④	⑥ Lane Group	⑦ Flow rate in Lane Group v_g (vph)	⑧ Number of Lanes N	⑨ Lane Utilization Factor U Table 9-4	⑩ Adj. Flow v (vph) ⑦ × ⑨	⑪ Prop. of LT or RT P_{LT} or P_{RT}
EB	LT	131	0.91	146	↲	708	2	1.05	744	
	TH	506	0.91	562	↩←					
	RT									
WB	LT	344	0.91	382	↗	1325	2	1.05	1391	
	TH	849	0.91	943	→↴					
	RT									
NB	LT	88	0.91	98	←↓→	378	1	1.0	378	
	TH	252	0.91	280						
	RT									
SB	LT	96	0.91	107	←↑→	357	1.0	357		
	TH	225	0.91	250						
	RT									



Effect of approach width on saturation flow

Optimum Signal Time Phasing:

	N	S	E	W
q	378	357	744	1391
S	1900	1880	2250	1950
y=q/S	0.199	0.189	0.33	0.713

$$Y = 0.199 + 0.189 + 0.330 + 0.713$$

$$= 1.431$$

In this case, since $Y = \sum y > 1.0$ then, use the maximum recommended cycle length = 120 seconds.

Splitting Effective Green Times:

$$g_i = \frac{y_i}{Y} (C_o - L)$$

$$g_N = \frac{0.199}{1.431} (120 - 12) = 15.0$$

$$g_S = 0.189 * 75.472 = 14.3$$

$$g_E = 0.330 * 75.472 = 24.9$$

$$g_W = 0.713 * 75.472 = 53.8$$

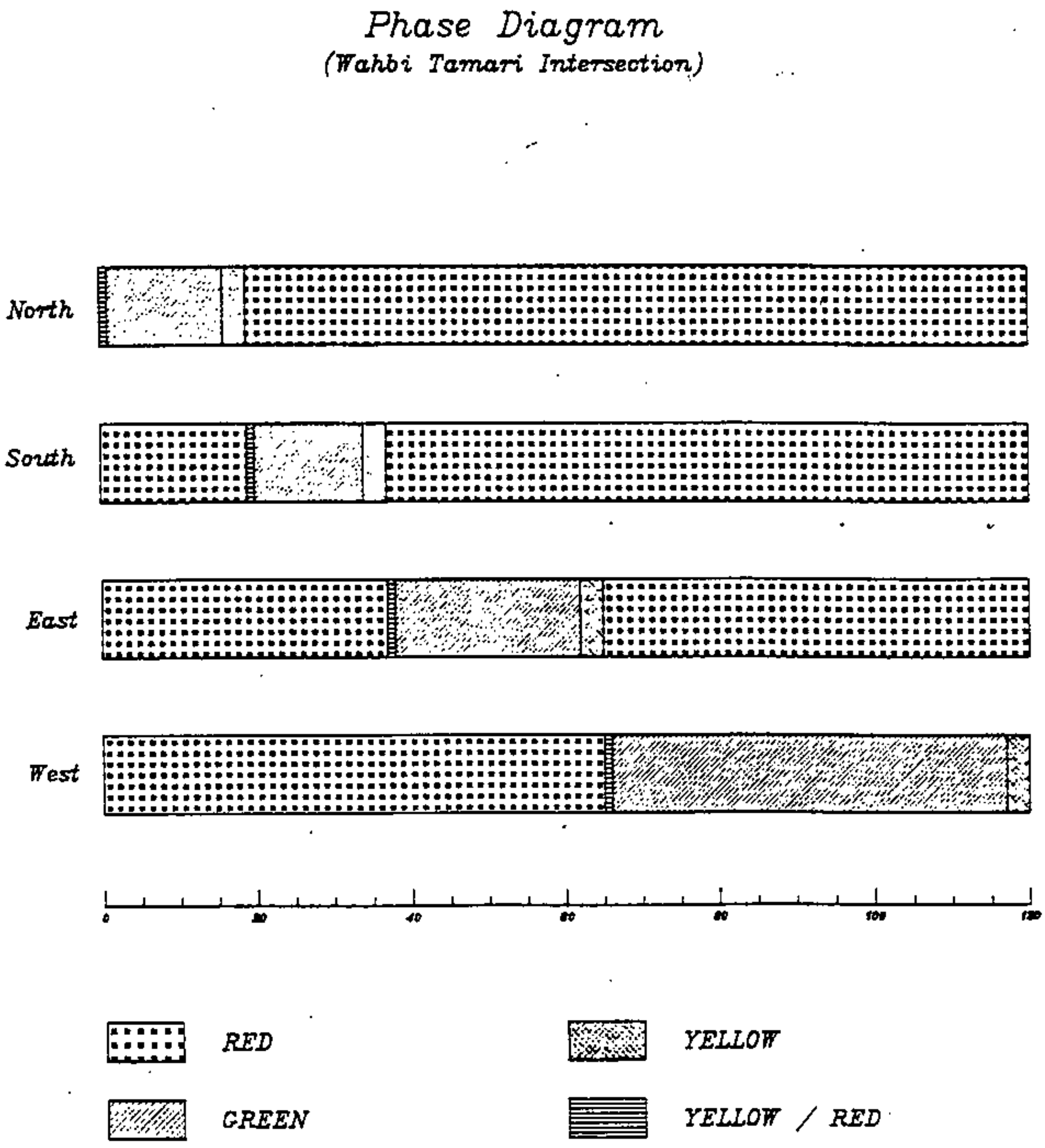
Then, actual green times (Refer to figure on next page)

g_N = 15 sec

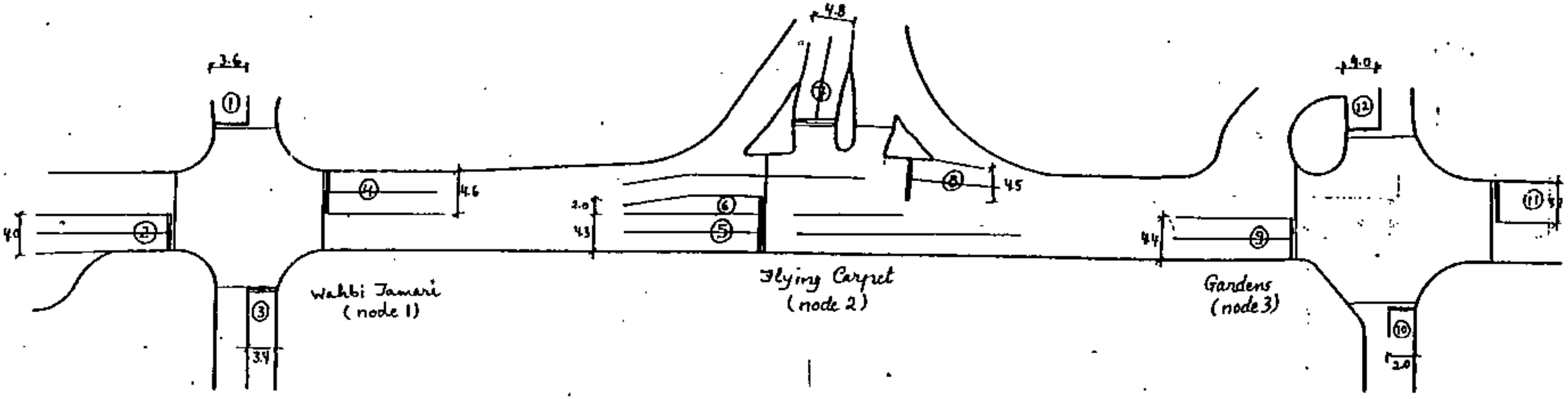
g_S = 14 sec

g_E = 24 sec

g_W = 51 sec.



Phase diagram of Wahbi Tamari Intersection in the a.m. peak hour


①
3.6
②
4.0
③
3.4
④
4.6
⑤
⑥
2.0
4.3
⑦
4.8
⑧
4.5
⑨
4.4
⑩
2.0
⑪
⑫
4.0
Wahbi Tamari
(node 1)
Flying Carpet
(node 2)
Gardens
(node 3)

TRANSYT-7F

NODE/LINK INVENTORY WORKSHEET

CITY Amman NETWORK Prince Shaker st.

SYSTEM ____________

CONDITION(S) ____________ PERIOD ____________

DEVELOPED BY ____________ DATE ____________

INVENTORY

INTERSECTION	NODE NO.	LINK NO.	LINK LENGTH	SAT. FLOW	COMMENTS/SPECIAL ACTIONS
Wabbi	1	101	200	1900	External , Primary
Tamari		102	200		" , Secondary
		103	200		" , "
		104	200	1880	External , Primary
		105	200		" , Secondary
		106	200		" , "
		107	400	1950	External , Primary
		108	400		" , Secondary
		109	400		" , "
		110	426	2250	Primary
		111	426		Secondary
		112	426		"

SHEET ___ OF ___

TRANSYT-7F

NODE/LINK INVENTORY WORKSHEET

CITY Amman NETWORK Prince Shaker str.

SYSTEM ____________

CONDITION(S) ____________ PERIOD ____________

DEVELOPED BY ____________ DATE ____________

INVENTORY

INTERSECTION	NODE NO.	LINK NO.	LINK LENGTH	SAT. FLOW	COMMENTS/SPECIAL ACTIONS
Flying Carpet	2	201	400	2420	External,
		202	400	1200	External, Permitted right
					turn 100% green
		204	426	2075	Primary
		205	426	1100	Primary
		206	177	2215	Primary
		207	177	1200	Permitted right turn
					100% green

SHEET ___ OF ___

TRANSYT-7F
NODE/LINK INVENTORY WORKSHEET

CITY Amman NETWORK Prince Shaker str.

SYSTEM

CONDITION(S) PERIOD

DEVELOPED BY DATE

INVENTORY

INTERSECTION	NODE NO.	LINK NO.	LINK LENGTH	SAT. FLOW	COMMENTS/SPECIAL ACTIONS
Gardens	3	301	300	1950	External , Primary
		302	300	1200	Permitted
		303	300		External , Secondary
		304	600	1100	External , Primary
		305	600		" , Secondary
		306	600		" "
		307	177	2150	Primary
		308	177		Secondary
		309	300	2150	External , Primary
		310	300		" , Secondary

SHEET ___ OF ___

TRANSYT-7F

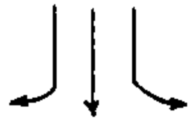
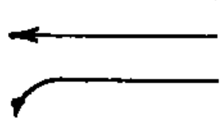
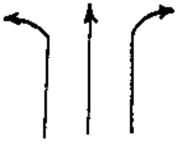
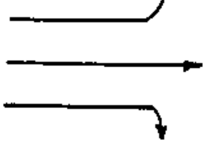
DATA COLLECTION SHEET - PRETIMED SIGNAL - TIMING PLAN

CITY Amman NETWORK Prince Shaker Str.

INTERSECTION Wahbi Tamari NODE 1

CONTROLLER

COLLECTED BY SOURCE DATE

INTERVAL		DIAL NUMBER									PHASES		
		1			2			3					
NAME	NO.	SEC	%	PIN	SEC	%	PIN	SEC	%	PIN	DIAGRAM	NO.	MIN
Actual green	1	12										1	17 Sec
Yellow/Red	2	1											
Amber	3	3											
All/Red	4	1											
Actual Green	5	22										2	27 Sec.
Yellow/Red	6	1											
Amber	7	3											
All/Red	8	1											
Actual Green	9	13										3	18 Sec
Yellow/Red	10	1											
Amber	11	3											
All/Red	12	1											
ActualGreen	13	33										4	38 Sec
Yellow/Red	14	1											
Amber	15	3											
All/Red	16	1											
CYCLE LENGTHS		100 sec.									COMMENTS		
OFFSETS	1												
	2												
	3												
TIMES/DIAL													

SHEET ___ OF ___

TRANSYT-7F

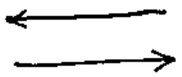
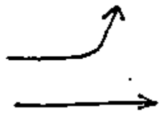
DATA COLLECTION SHEET - PRETIMED SIGNAL - TIMING PLAN

CITY Amman NETWORK Prince Shaker St.

INTERSECTION Flying Carpet NODE 2

CONTROLLER

COLLECTED BY SOURCE DATE

INTERVAL		DIAL NUMBER									PHASES		
		1			2			3					
NAME	NO.	SEC	%	PIN	SEC	%	PIN	SEC	%	PIN	DIAGRAM	NO.	MIN
Actual Green	1	28										1	33 Sec
Yellow/Red	2	1											
Amber	3	3											
All Red	4	1											
Actual Green	5	23										2	28 Sec
Yellow/Red	6	1											
Amber	7	3											
All Red	8	1											
Actual Green	9	34										3	39 sec
Yellow/Red	10	1											
Amber	11	3											
All Red	12	1											
CYCLE LENGTHS		100 Sec									COMMENTS		
OFFSETS	1												
	2												
	3												
TIMES/DIAL													

SHEET __ OF __

TRANSYT-7F

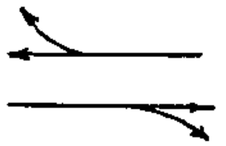
DATA COLLECTION SHEET · PRETIMED SIGNAL · TIMING PLAN

CITY Amman NETWORK Prince Shaker st.

INTERSECTION Gardens NODE 3

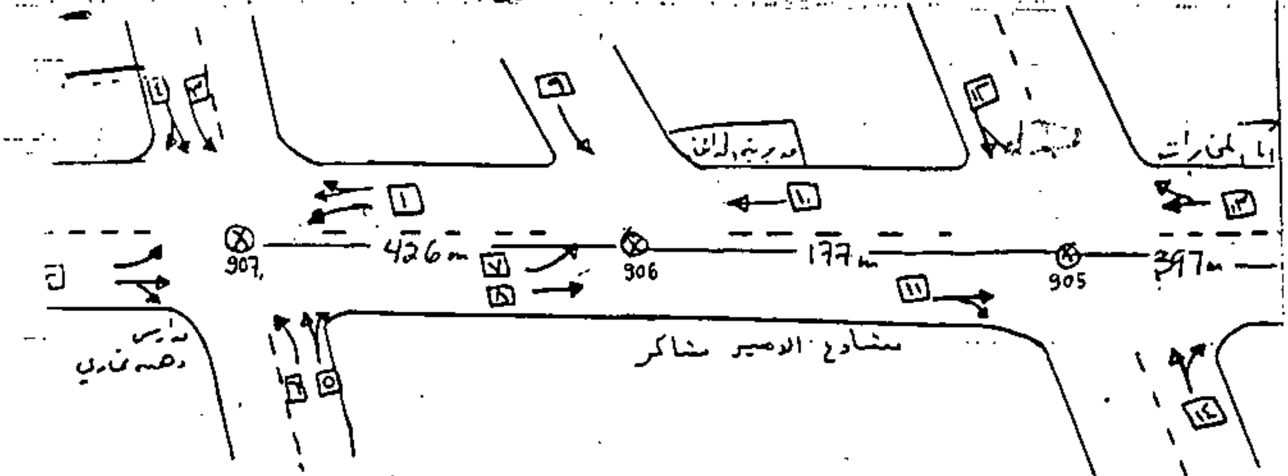
CONTROLLER

COLLECTED BY SOURCE DATE

INTERVAL		DIAL NUMBER									PHASES		
		1			2			3					
NAME	NO.	SEC	%	PIN	SEC	%	PIN	SEC	%	PIN	DIAGRAM	NO.	MIN
Actual Gr.		43										1	48 sec
Yellow/Red		1											
Amber		3											
All/Red		1											
Actual Gr.		23		—								2	28 sec
Yellow/Red		1											
Amber		3											
All/Red		1											
Actual Gr.		19										3	24 sec
Yellow/Red		1											
Amber		3											
All/Red		1											
CYCLE LENGTHS		100 Sec									COMMENTS		
OFFSETS	1												
	2												
	3												
TIMES/DIAL													

SHEET ___ OF ___

TRAFFIC CUUNIS: Period: 7:30-9:30



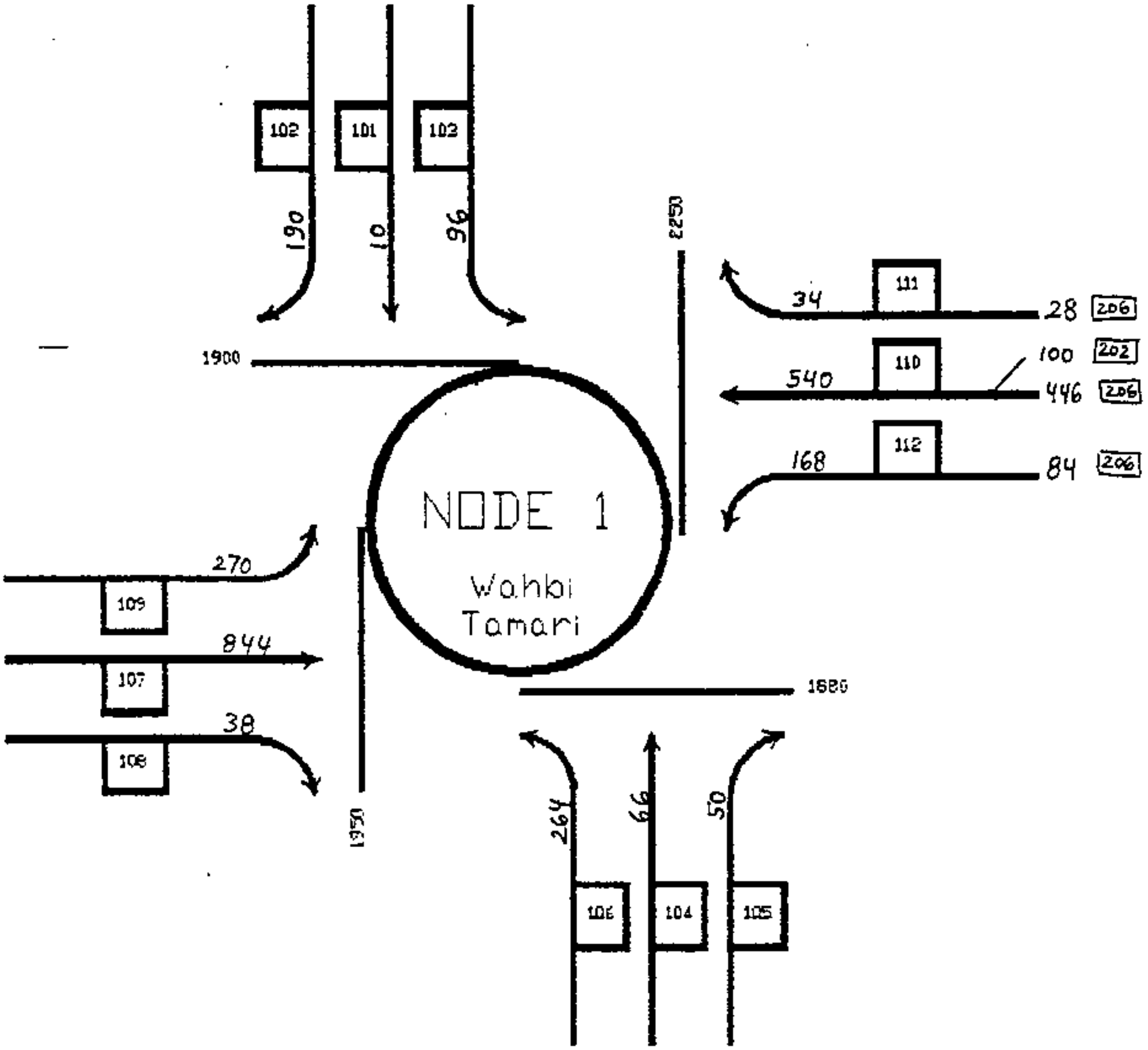
MOVCMENT IME PERIOD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
7.00 - 7.15															
7.15 - 7.30															
7.30 - 7.45	120/40	233/60	22	78	23	62	91	220	203	146	343	114	201	80	
7.45 - 8.00	116/46	206/125	36	71	28	64	97	222	212	133	378	172	236	117	
8.00 - 8.15	171/38	197/34	22	56	30	68	83	204	213	100	355	140	239	62	
8.15 - 8.30	99/7	211/75	18	47	15	31	89	208	191	96	326	91	201	48	
8.30 - 8.45	129/12	198/55	16	32	14	15	85	168	164	128	325	88	155	40	
8.45 - 9.00	149/15	184/45	11	44	13	16	42	101	158	149	253	83	169	35	
9.00 - 9.15	145/13	197/70	10	21	9	10	66	130	119	96	282	93	203	33	
9.15 - 9.30	184/10	192/50	15	27	17	19	71	166	120	101	226	79	178	36	
9.30 - 9.45															
9.45 - 10.00															
Sub total															
TOTAL															

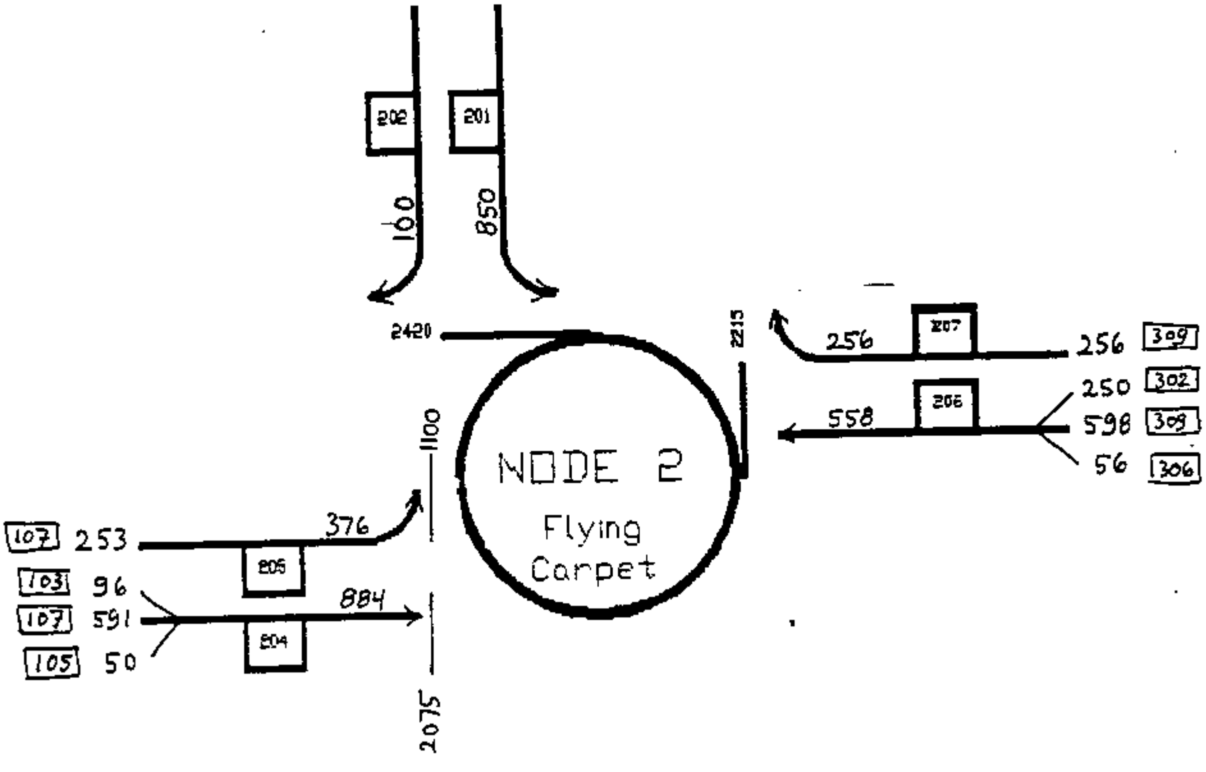
Intersection: 905, 906, 907

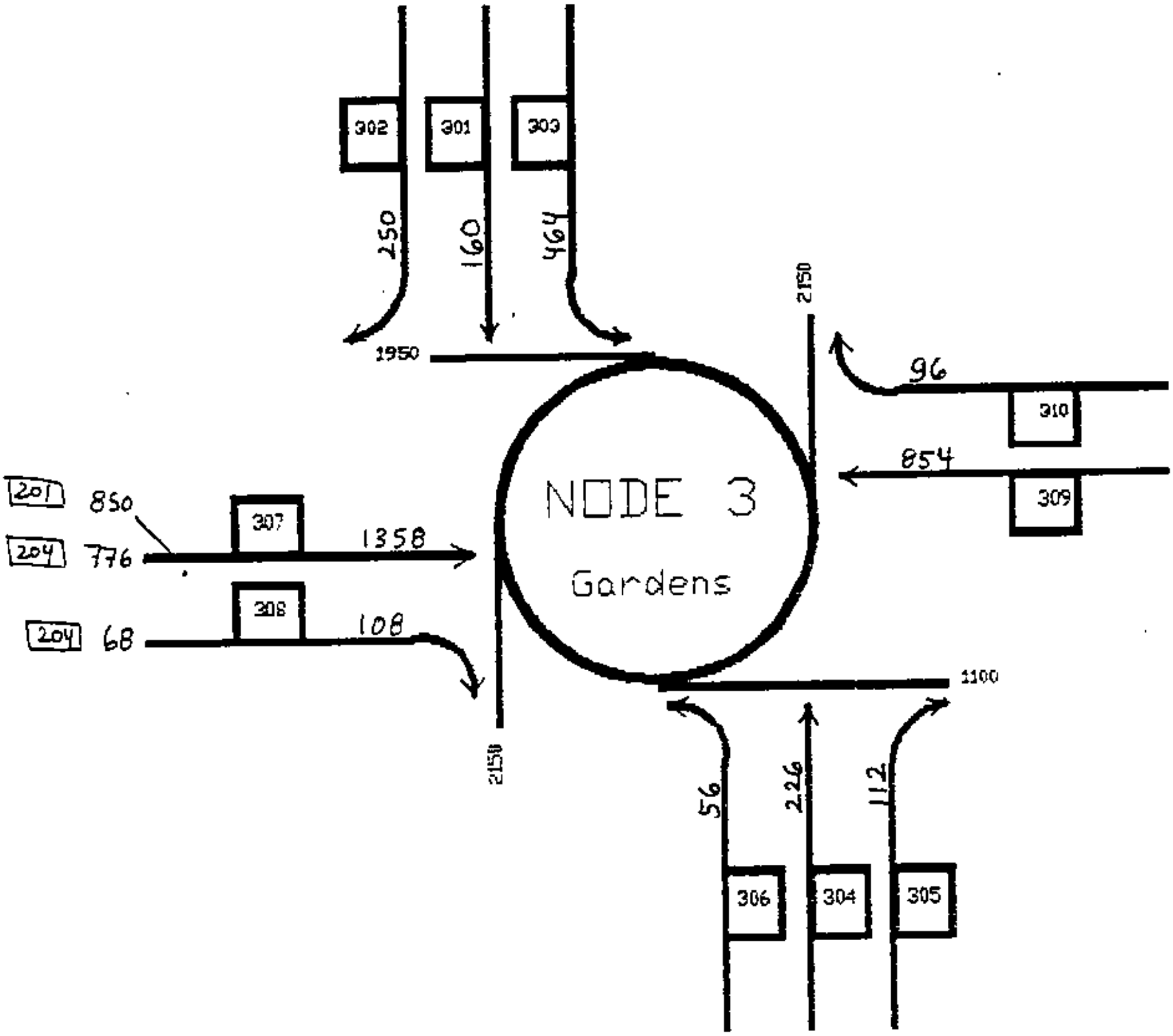
Date : 29/5/1989

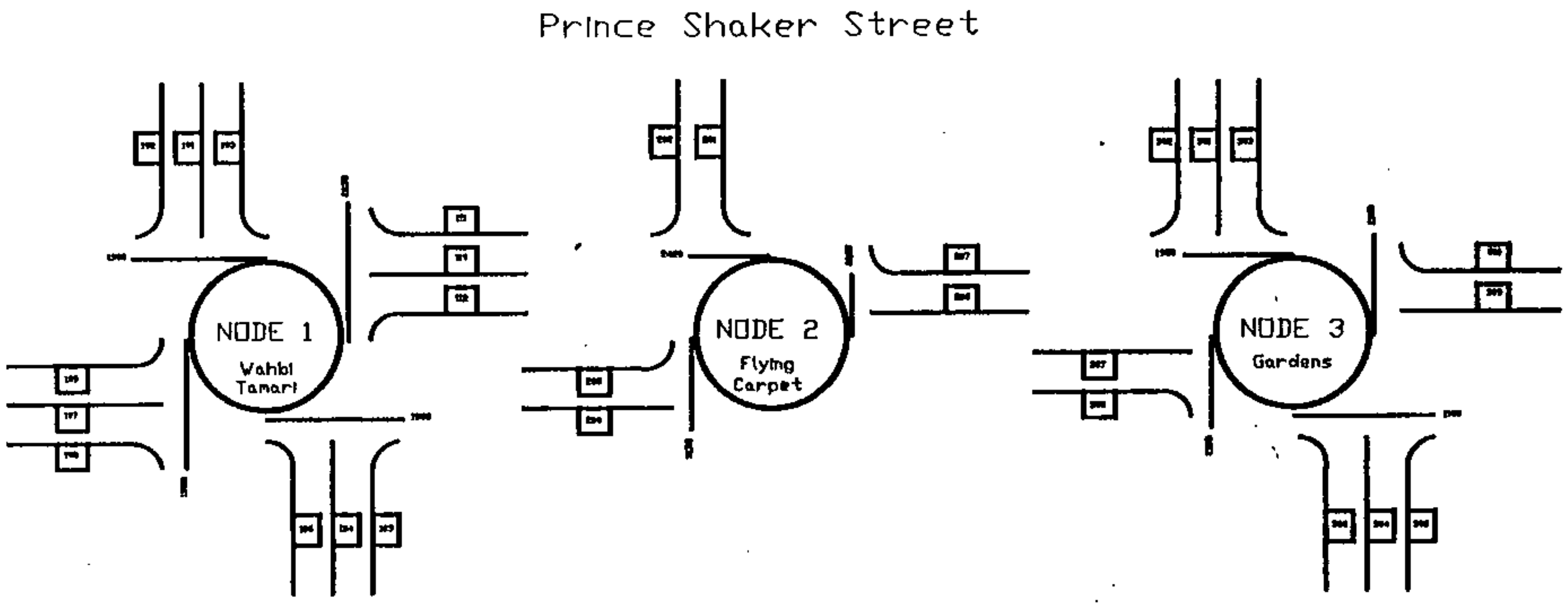
Day : Tuesday

Weather Conditions : Sunny


102
101
103
190
10
96
2253
1900
NODE 1
Wahbi
Tamari
111
34
28
206
110
540
100
202
446
206
112
168
84
206
270
109
844
107
38
108
1950
1680
264
66
50
106
104
105


NODE 2
Flying
Carpet
202
201
160
850
2420
2215
1100
2075
256
207
256
309
250
302
558
206
598
309
56
306
107
253
376
205
103
96
884
107
591
204
105
50


302
301
303
250
160
464
1950
2150
96
310
854
309
NODE 3
Gardens
201
850
204
776
307
1358
204
68
308
108
2150
1100
56
226
112
306
304
305



Schematic Node/Link Diagram

TRANSYT-7F

DATA COLLECTION SHEET - TOTAL VOLUME COUNT STUDY

CITY Amman NETWORK Prince Shaker St.

LOCATION Walbi Tamari

NODES IN INFLUENCE AREA 1

COLLECTED BY

COMPLETED BY DATE

COMMENTS

	TIME PERIOD	DAY% DAY/DATE OF COUNTS							
		MON.	TUES.	WED.	THURS.	FRI.	WEEK TOTAL	AVERAGE	DESIGN PERIOD AND HOURS
North	7:30-7:45		100						½ Hr Peak
	7:45-8:00		97						
	8:00-8:15		78						
	8:15-8:30		65						
	8:30-8:45		48						
	8:45-9:00		55						
	9:00-9:15		31						
	9:15-9:30		42						
South	7:30-7:45		153						½ Hr Peak
	7:45-8:00		161						
	8:00-8:15		151						
	8:15-8:30		120						
	8:30-8:45		100						
	8:45-9:00		58						
	9:00-9:15		76						
	9:15-9:30		90						

SHEET ___ OF ___

TRANSYT-7F

DATA COLLECTION SHEET - TOTAL VOLUME COUNT STUDY

CITY Amman NETWORK Prince Shaker St.

LOCATION Wahbi Tamari

NODES IN INFLUENCE AREA 1

COLLECTED BY

COMPLETED BY DATE

COMMENTS

	TIME PERIOD	DAY% DAY/DATE OF COUNTS							
		MON.	TUES.	WED.	THURS.	FRI.	WEEK TOTAL	AVERAGE	DESIGN PERIOD AND HOURS
East	7:30-7:45		160						
	7:45-8:00		162						½ Hr Peak
	8:00-8:15		209						
	8:15-8:30		106						
	8:30-8:45		141						
	8:45-9:00		164						
	9:00-9:15		158						
	9:15-9:30		196						
West	7:30-7:45		295						½ Hr Peak
	7:45-8:00		331						
	8:00-8:15		281						
	8:15-8:30		286						
	8:30-8:45		253						
	8:45-9:00		225						
	9:00-9:15		263						
	9:15-9:30		244						

SHEET___ OF ___

TRANSYT-7F
DATA COLLECTION SHEET : TOTAL VOLUME COUNT STUDY

CITY Amman NETWORK Prince Shaker St.

LOCATION Flying Carpet

NODES IN INFLUENCE AREA 1

COLLECTED BY

COMPLETED BY DATE

COMMENTS

	TIME PERIOD	DAY% DAY/DATE OF COUNTS							
		MON.	TUES.	WED.	THURS.	FRI.	WEEK TOTAL	AVERAGE	DESIGN PERIOD AND HOURS
North	7:30-7:45		203						½ Hr Peak
	7:45-8:00		212						
	8:00-8:15		213						
	8:15-8:30		191						
	8:30-8:45		184						
	8:45-9:00		158						
	9:00-9:15		119						
	9:15-9:30		120						
East	7:30-7:45		146						½ Hr Peak
	7:45-8:00		133						
	8:00-8:15		100						
	8:15-8:30		96						
	8:30-8:45		128						
	8:45-9:00		149						
	9:00-9:15		96						
	9:15-9:30		101						
West	7:30-7:45		311						½ Hr Peak
	7:45-8:00		319						
	8:00-8:15		287						
	8:15-8:30		297						
	8:30-8:45		253						
	8:45-9:00		143						
	9:00-9:15		196						
	9:15-9:30		237						

SHEET ___ OF ___

TRANSYT-7F
DATA COLLECTION SHEET - TOTAL VOLUME COUNT STUDY

CITY Amman NETWORK Prince Shaker St.

LOCATION Gardens

NODES IN INFLUENCE AREA 1

COLLECTED BY

COMPLETED BY DATE

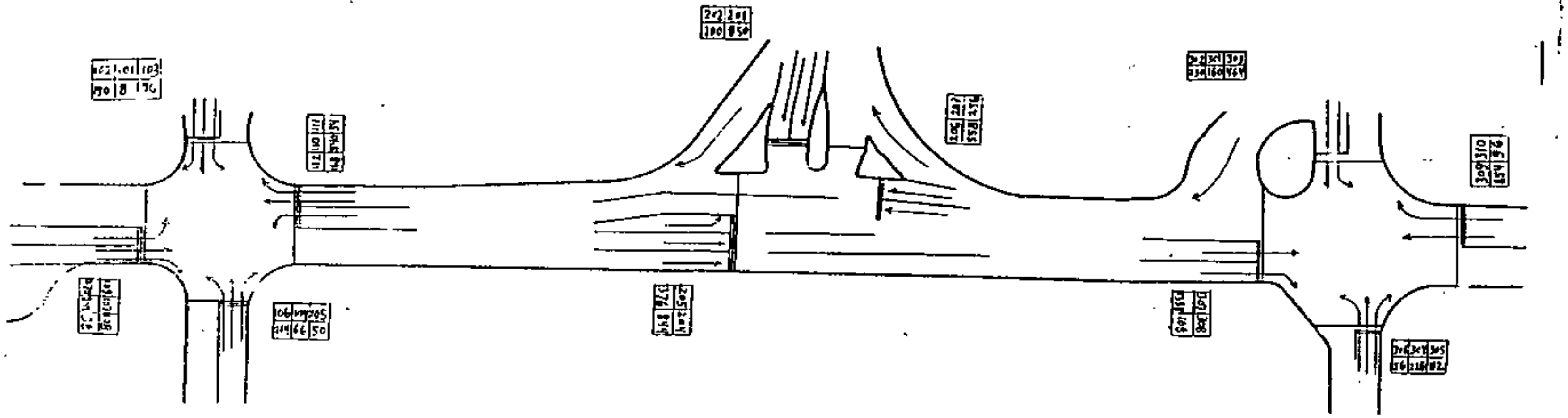
COMMENTS

	TIME PERIOD	DAY% DAY/DATE OF COUNTS					WEEK TOTAL	AVERAGE	DESIGN PERIOD AND HOURS
		MON.	TUES.	WED.	THURS.	FRI.			
North	7:30-7:45		114						
	7:45-8:00		172						1/2 Hr Peak
	8:00-8:15		140						
	8:15-8:30		91						
	8:30-8:45		88						
	8:45-9:00		83						
	9:00-9:15		93						
	9:15-9:30		79						
South	7:30-7:45		80						1/2 Hr Peak
	7:45-8:00		117						
	8:00-8:15		62						
	8:15-8:30		48						
	8:30-8:45		40						
	8:45-9:00		35						
	9:00-9:15		33						
	9:15-9:30		36						
East-West	7:30-7:45		343		201				
	7:45-8:00		378		236				
	8:00-8:15		355		239				
	8:15-8:30		326		201				
	8:30-8:45		325		155				
	8:45-9:00		253		169				
	9:00-9:15		282		203				
	9:15-9:30		226		178				

SHEET ___ OF ___

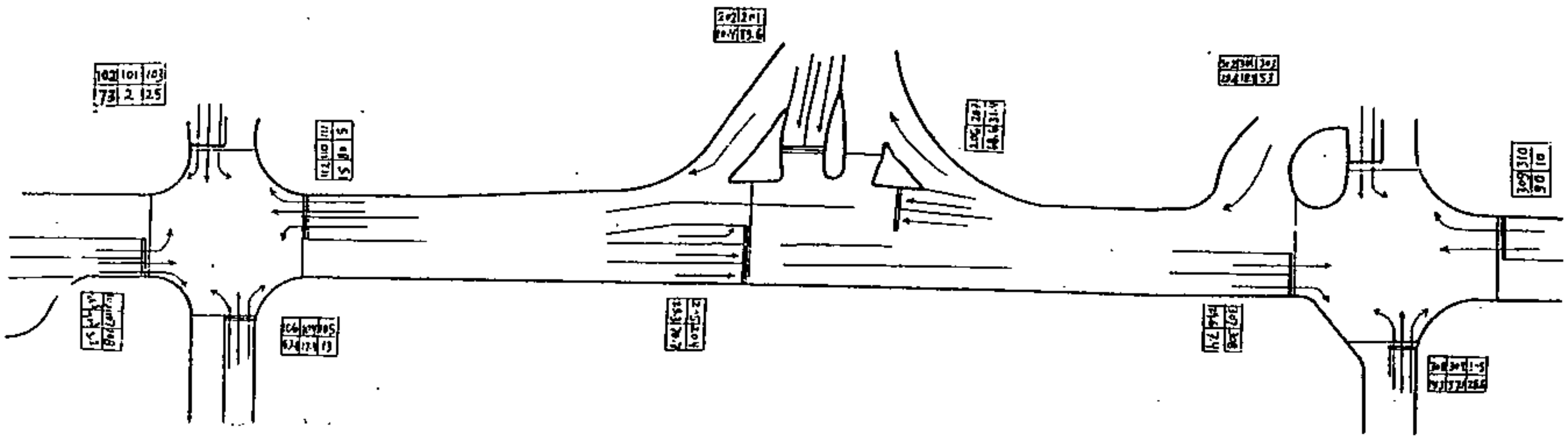
Total Volumes and Turning Movements

Design Hourly Volumes (DHV)



Total Flow By Link and By Movement (percentages)

Period 8:00 – 8:15
Sunday Sep 9, 1990



TRANSYT-7F

DATA COLLECTION SHEET - TURNING MOVEMENT COUNTS

CITY Amman NETWORK Prince Shaker St.

INTERSECTION Wahbi Tamari NODE NO. 1 PERIOD

COLLECTED BY DATE COMMENT/WEATHER

	A AVE.										1 ST										
	NORTHBOUND					SOUTHBOUND					EASTBOUND					WESTBOUND					
TIME PERIOD	LEFT	THRU	RT	RTOR	TOT.	LEFT	THRU	RT	RTOR	TOT.	LEFT	THRU	RT	RTOR	TOT.	LEFT	THRU	RT	RTOR	TOT.	GRAND TOTAL
7:30 – 7:45	22	2	76		100	62	13	10		85	40	113	7		160	60	225	10		295	640
– 8:00	26	2	69		97	64	16	12		92	46	109	7		162	125	197	9		331	682
– 8:15	22	2	54		78	68	17	13		98	38	161	10		209	84	188	9		281	666
– 8:30	18	1	46		65	31	9	6		46	7	93	6		106	75	202	9		286	503
PEAK 30 MIN	48	4	145		197	132	33	25		190	84	270	17		371	185	422	19		626	

TRANSYT-7F

DATA COLLECTION SHEET - TURNING MOVEMENT COUNTS

CITY Amman NETWORK Prince Shaker St.

INTERSECTION Flying Carpet NODE NO. 2 PERIOD

COLLECTED BY DATE COMMENT/WEATHER

	A AVE.										1 ST										
	NORTHBOUND					SOUTHBOUND					EASTBOUND					WESTBOUND					
TIME PERIOD	LEFT	THRU	PERM	RTOR	TOT.	LEFT	THRU	RTOG	RTOR	TOT.	LEFT	THRU	PERM	RTOR	TOT.	LEFT	THRU	RTOG	RTOR	TOT.	GRAND TOTAL
7:30–7:45	203		24		203							146	67		146	91	220			311	660
–8:00	212		25		212							133	61		133	97	222			319	664
–8:15	213		25		213							100	46		100	83	204			287	600
–8:30	191		22		191							96	44		96	89	208			297	584
PEAK 30 MIN	425				425							279			279	188	442			630	

TRANSYT-7F

DATA COLLECTION SHEET - TURNING MOVEMENT COUNTS

CITY Amman
NETWORK Prince Shaker St.
INTERSECTION Gardens
NODE NO. 3
PERIOD
COLLECTED BY
DATE
COMMENT/WEATHER

	A AVE.										1 ST										
	NORTHBOUND					SOUTHBOUND					EASTBOUND					WESTBOUND					
TIME PERIOD	LEFT	THRU	PERM	RTOR	TOT.	LEFT	THRU	RT	RTOR	TOT.	LEFT	THRU	RT	RTOR	TOT.	LEFT	THRU	RT	RTOR	TOT.	GRAND TOTAL
7:30 – 7:45	85	29	46		114	11	46	23		80		181	20		201		318	25		343	738
– 8:00	128	44	69		172	17	67	33		117		212	24		236		350	28		378	903
– 8:15	104	36	56		140	9	35	18		62		215	24		239		329	26		355	796
– 8:30	68	23	36		91	7	27	14		48		181	20		201		302	24		326	666
PEAK 30 MIN	232	80	125		312	28	113	56		197		427	48		475		679	54		733	

TRANSYT - 7F

DATA REDUCTION WORKSHEET - TOTAL VOLUMES AND TURNING MOVEMENTS

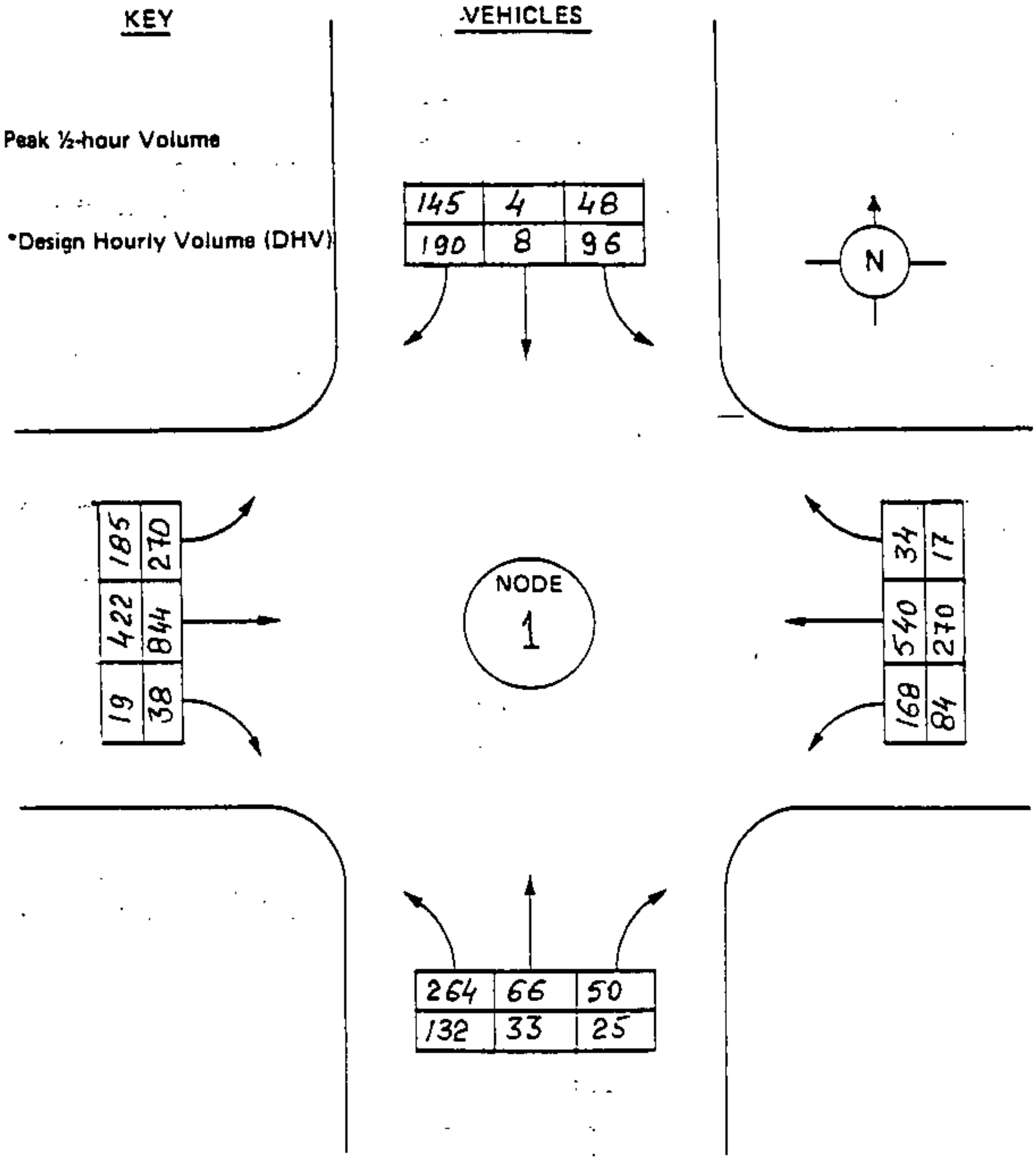
CITY Amman NETWORK Prince Shaker St.

INTERSECTION Wahbi Tamari NODE 1

COMPLETED BY DATE

REFERENCES PERIOD

COMMENTS



TRANSYT - 7F
DATA REDUCTION WORKSHEET - TOTAL VOLUMES AND TURNING MOVEMENTS

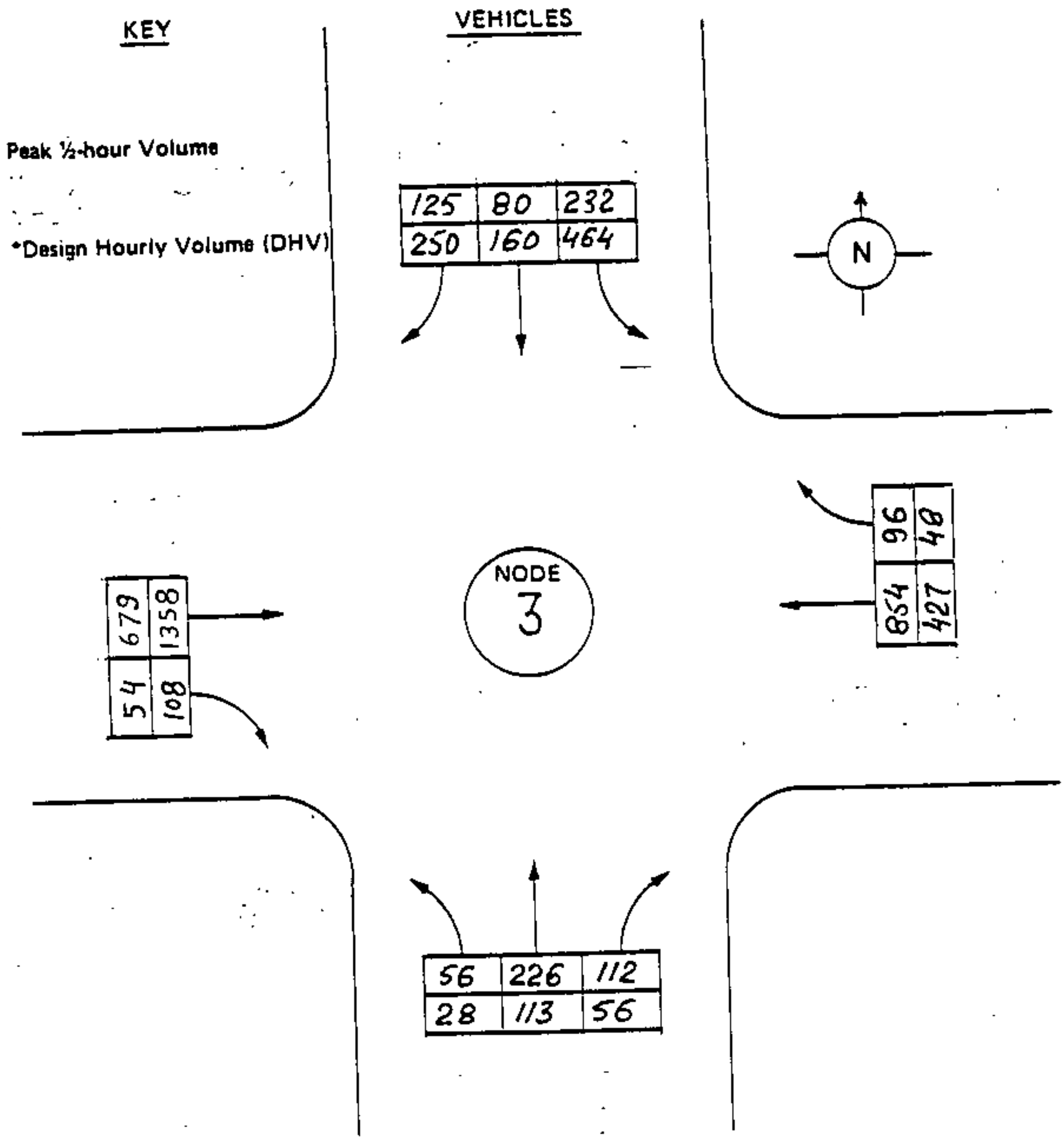
CITY ____________ NETWORK ____________

INTERSECTION Gardens NODE 3

COMPLETED BY ____________ DATE ____________

REFERENCES ____________ PERIOD ____________

COMMENTS ____________



TRANSYT - 7F

DATA REDUCTION WORKSHEET - TOTAL VOLUMES AND TURNING MOVEMENTS

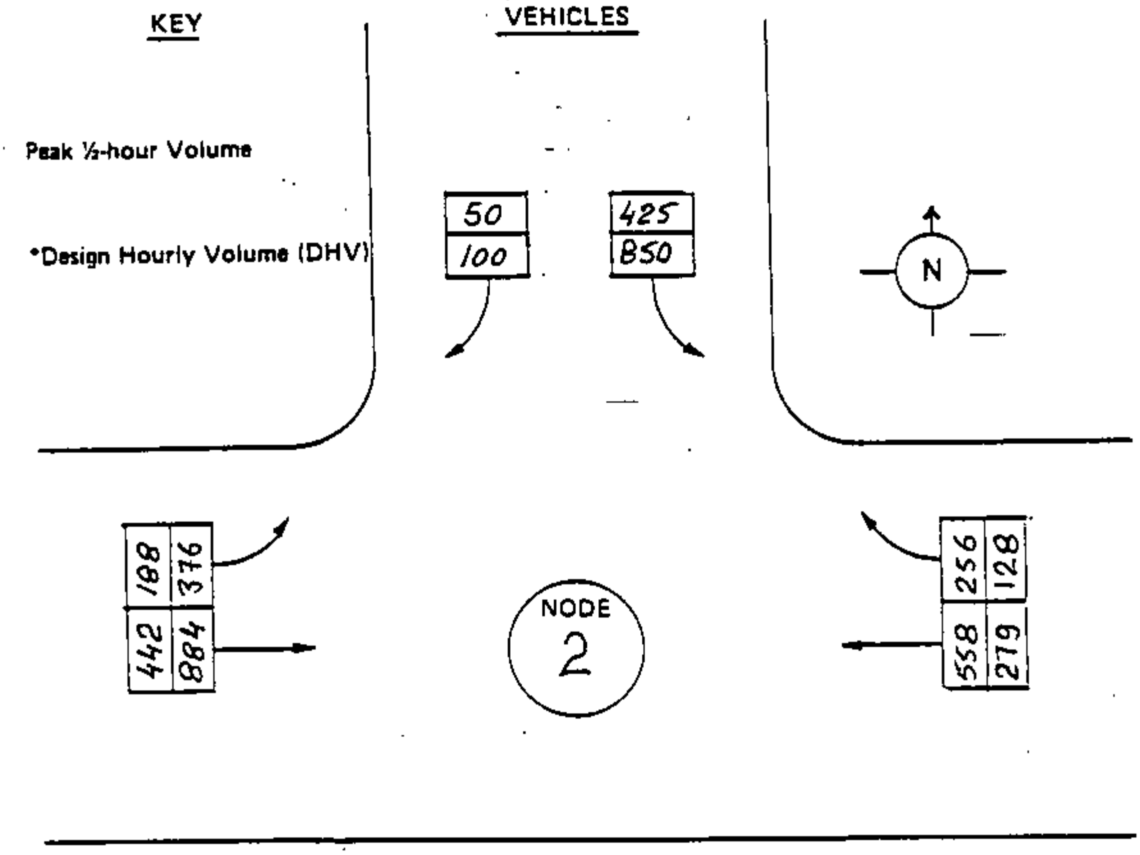
CITY ______ NETWORK ______

INTERSECTION *Flying Carpet* NODE 2

COMPLETED BY ______ DATE ______

REFERENCES ______ PERIOD ______

COMMENTS ______



TRANSYT - 7F

DATA REDUCTION WORKSHEET - TOTAL VOLUMES AND TURNING MOVEMENTS

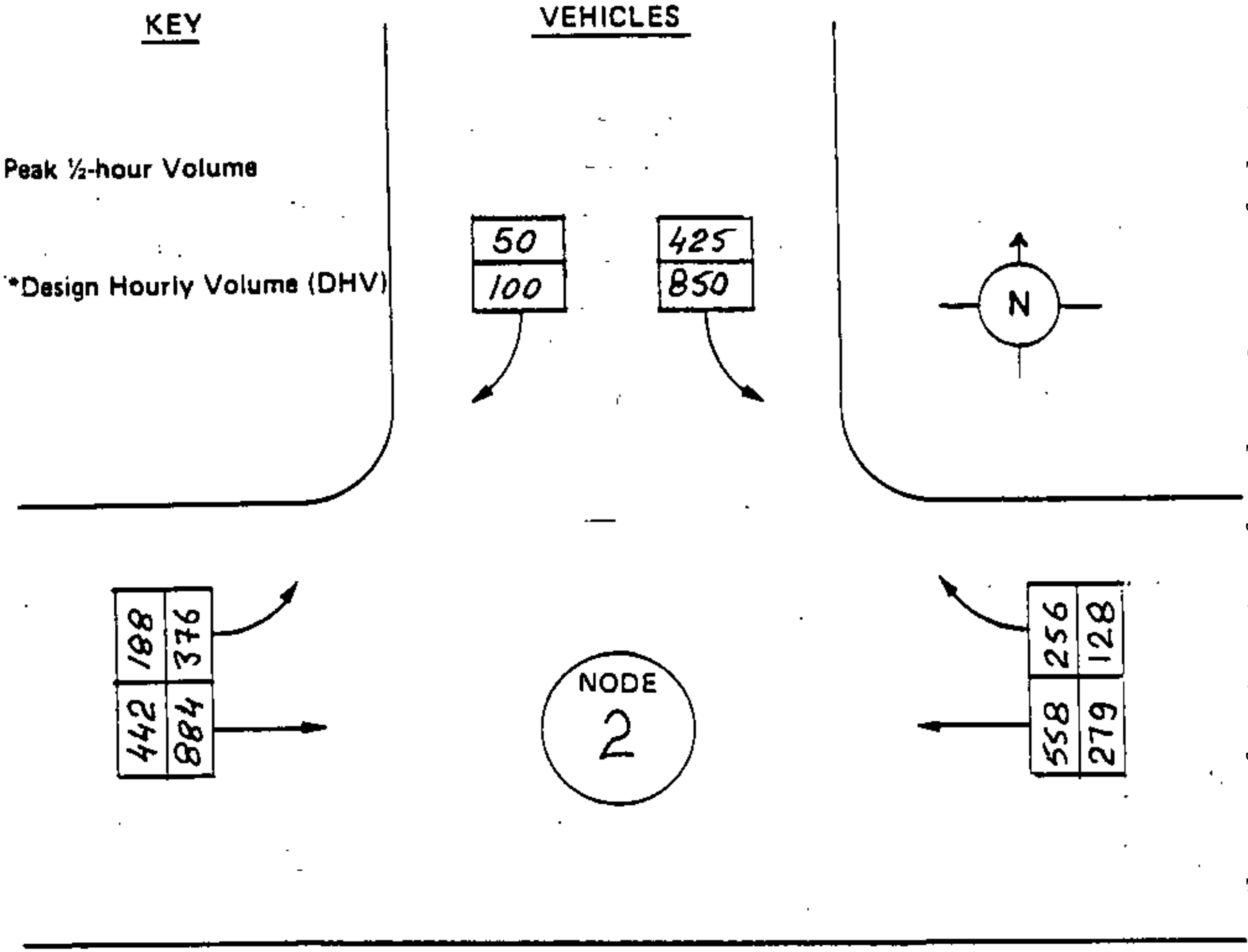
CITY ______ NETWORK ______

INTERSECTION Flying Carpet NODE 2

COMPLETED BY ______ DATE ______

REFERENCES ______ PERIOD ______

COMMENTS ______



TRANSYT - 7F

DATA COLLECTION SHEET - LINK-TO-LINK SAMPLES

CITY ______ NETWORK ______

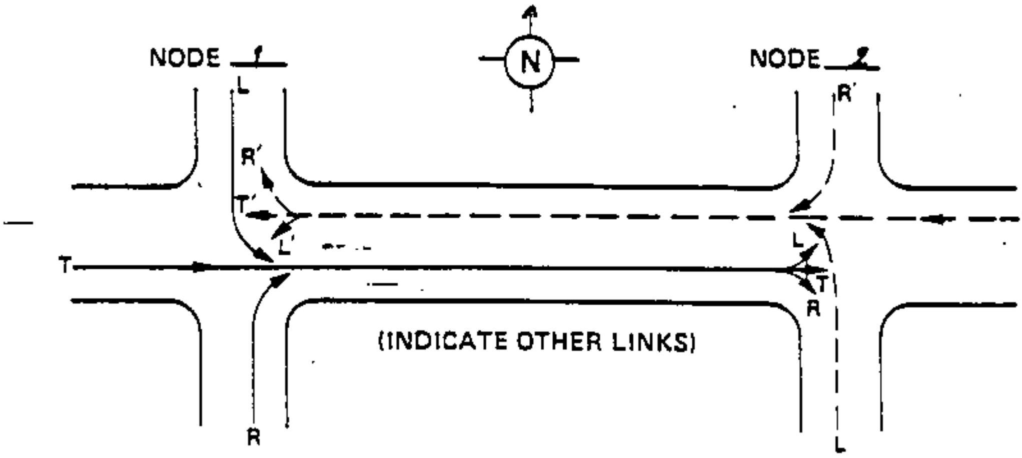
STREET ______ PERIOD ______

LEFT INTERSECTION wahbi Tamari NODE NO. 1

RIGHT INTERSECTION Flying Carpet NODE NO. 2

COLLECTED BY ______ DATE ______ WEATHER ______

COMMENT ______



LEFT TO RIGHT

		TO NODE 2				TOTAL
		L	T	R		
FROM NODE 1	L		96 100%			96
	T	254 30%	590 70%			844
	R		50 100%			50

RIGHT TO LEFT

TOTAL	TO NODE 1					
		L'	T'	R'		
100			100 100%		R'	FROM NODE 2
558		84 15%	446 80%	28 5%	T'	
					L'	

TRANSYT - 7F

DATA COLLECTION SHEET - LINK-TO-LINK SAMPLES

CITY Amman NETWORK Prince Shaker St.

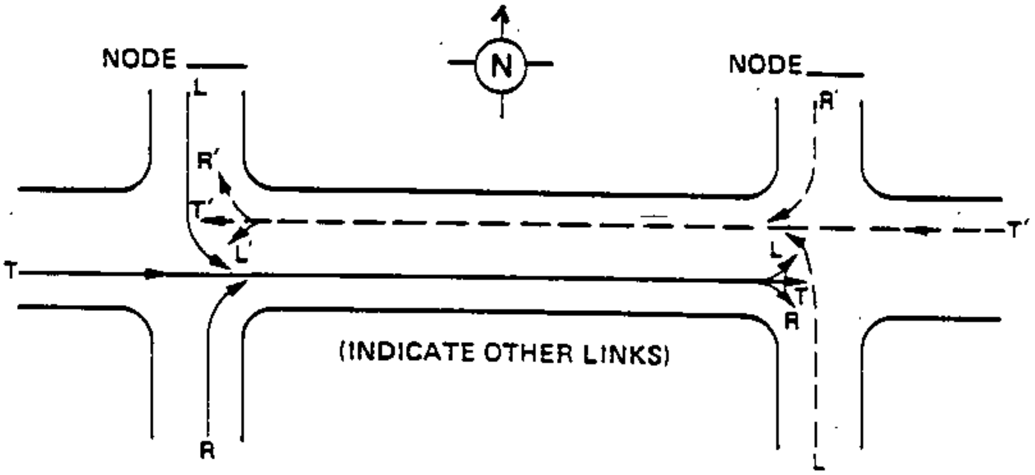
STREET PERIOD

LEFT INTERSECTION Flying Carpet NODE NO. 2

RIGHT INTERSECTION gardens NODE NO. 3

COLLECTED BY DATE WEATHER

COMMENT



LEFT TO RIGHT

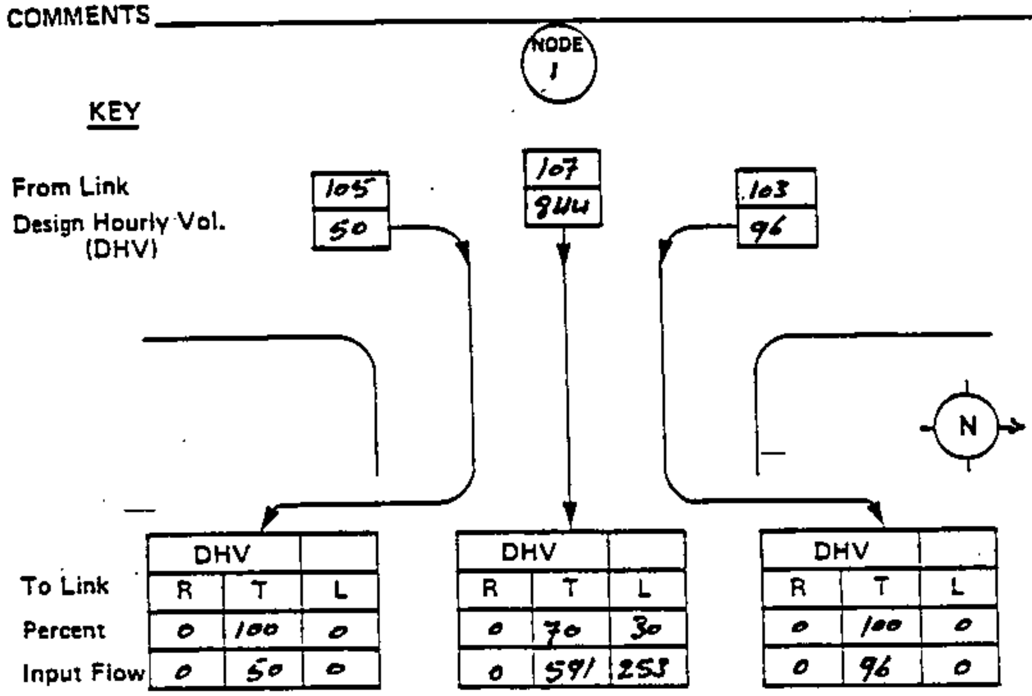
		TO NODE 3				TOTAL
		L	T	R		
FROM NODE 2	L		850 100%			850
	T		776 92%	68 8%		844
	R					

RIGHT TO LEFT

TOTAL	TO NODE 2					
		L'	T'	R'		
250			250 100%		R'	FROM NODE 3
854			598 70%	256 30%	T'	
56			56 100%		L'	

TRANSYT - 7F
DATA REDUCTION WORKSHEET - LINK INPUTS

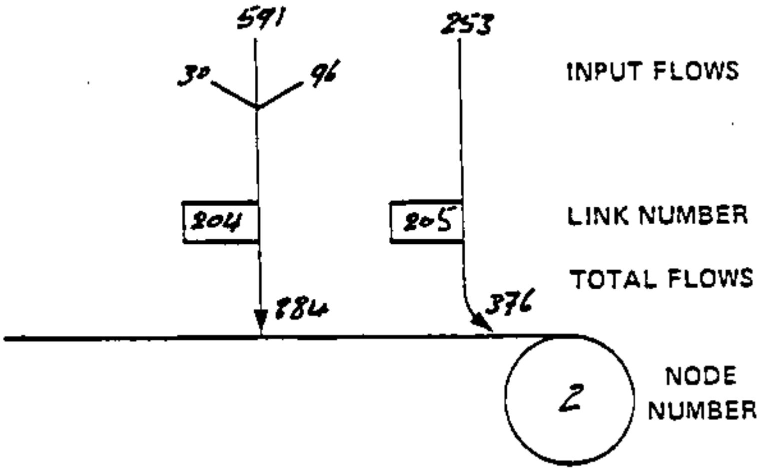
CITY Amman NETWORK Prince shaker St.
FROM INTERSECTION Wabbi Tamari NODE 1
TO INTERSECTION Flying Carpet NODE 2
COMPLETED BY DATE
REFERENCES PERIOD
COMMENTS



DHV		
R	T	L
0	100	0
0	50	0

DHV		
R	T	L
0	70	30
0	591	253

DHV		
R	T	L
0	100	0
0	96	0



TRANSYT - 7F

DATA REDUCTION WORKSHEET - LINK INPUTS

CITY Amman NETWORK Prince shaker st

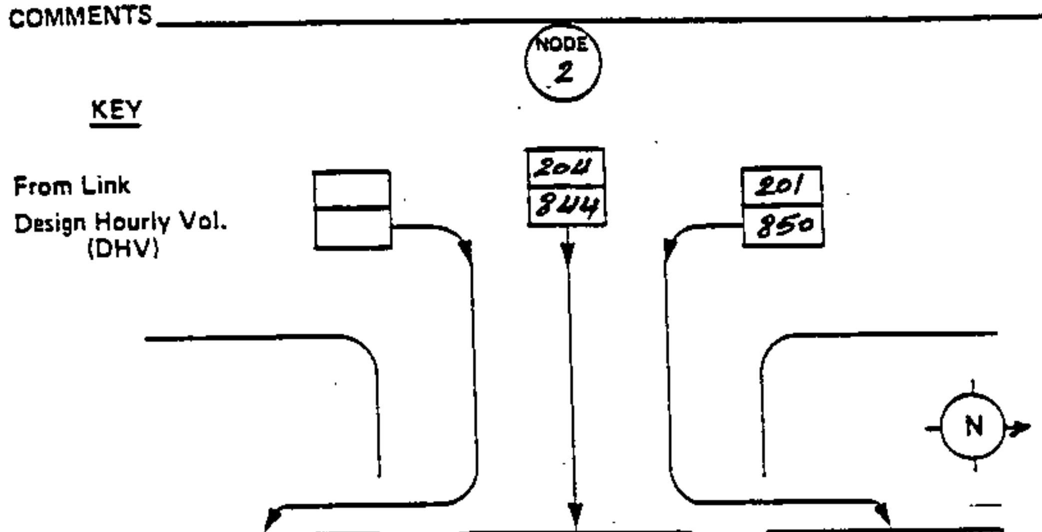
FROM INTERSECTION Flying Carpet NODE 2

TO INTERSECTION Gardens NODE 3

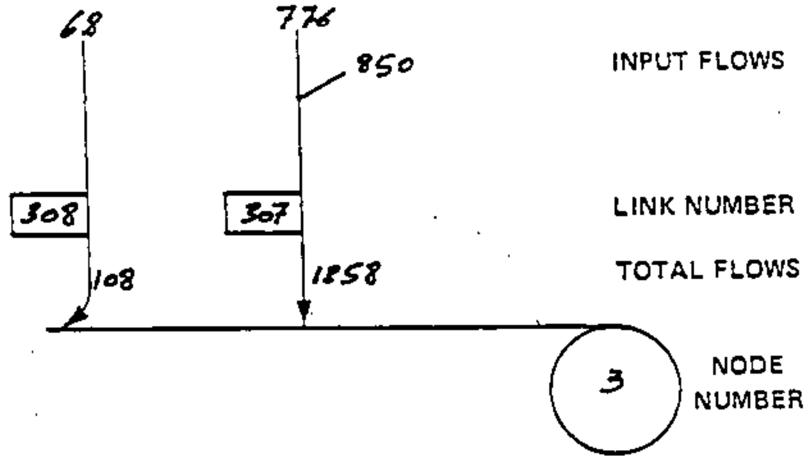
COMPLETED BY DATE

REFERENCES PERIOD

COMMENTS



	DHV			DHV			DHV		
To Link	R	T	L	R	T	L	R	T	L
Percent				8	92	0	0	100	0
Input Flow				68	776		0	850	0

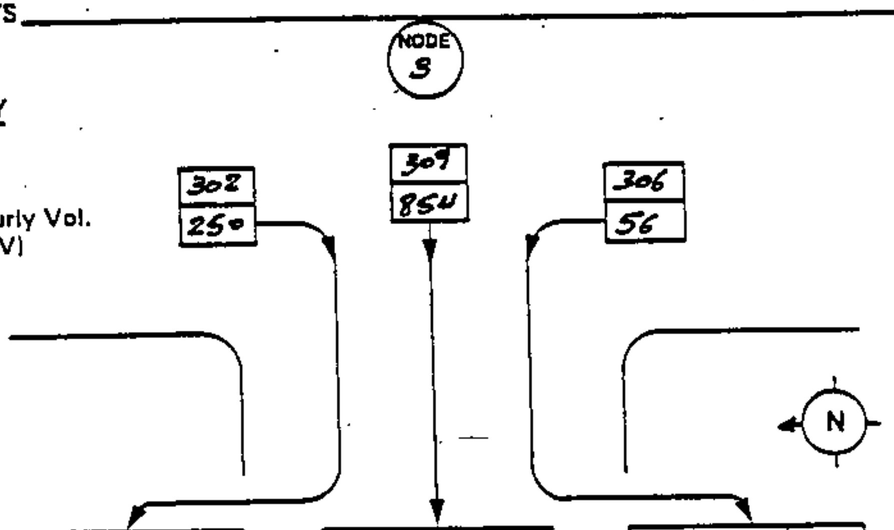


TRANSYT - 7F
DATA REDUCTION WORKSHEET - LINK INPUTS

CITY *Amman* NETWORK *Prince shaker st.*
FROM INTERSECTION *Gardens* NODE *3*
TO INTERSECTION *Flying Carpet* NODE *2*
COMPLETED BY DATE
REFERENCES PERIOD
COMMENTS

KEY

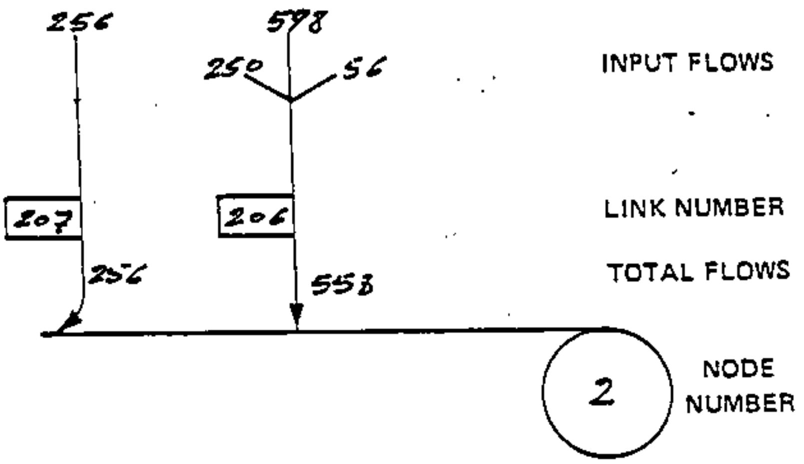
From Link
Design Hourly Vol. (DHV)



To Link	DHV		
	R	T	L
Percent	0	100	0
Input Flow	0	250	0

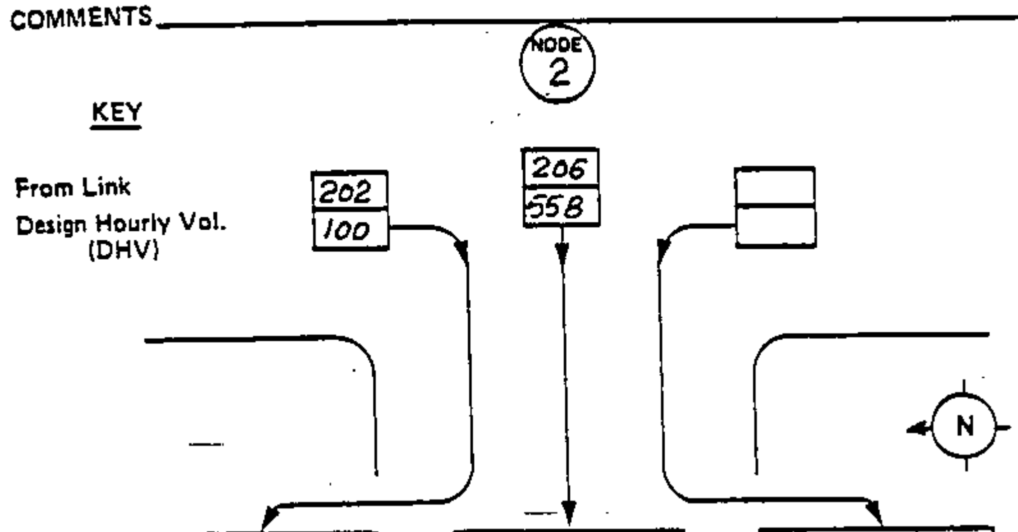
DHV		
R	T	L
30	70	0
256	598	0

DHV		
R	T	L
0	100	0
0	56	0



TRANSYT - 7F
DATA REDUCTION WORKSHEET - LINK INPUTS

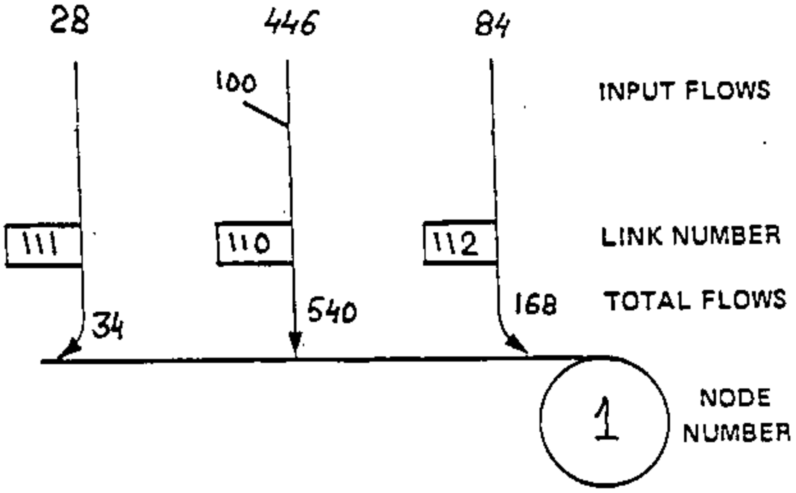
CITY Amman NETWORK Prince Shaker st.
FROM INTERSECTION Flying Carpet NODE 2
TO INTERSECTION Wasfi Tamari NODE 1
COMPLETED BY DATE
REFERENCES PERIOD
COMMENTS



	DHV		
To Link	R	T	L
Percent	0	100	0
Input Flow	0	100	0

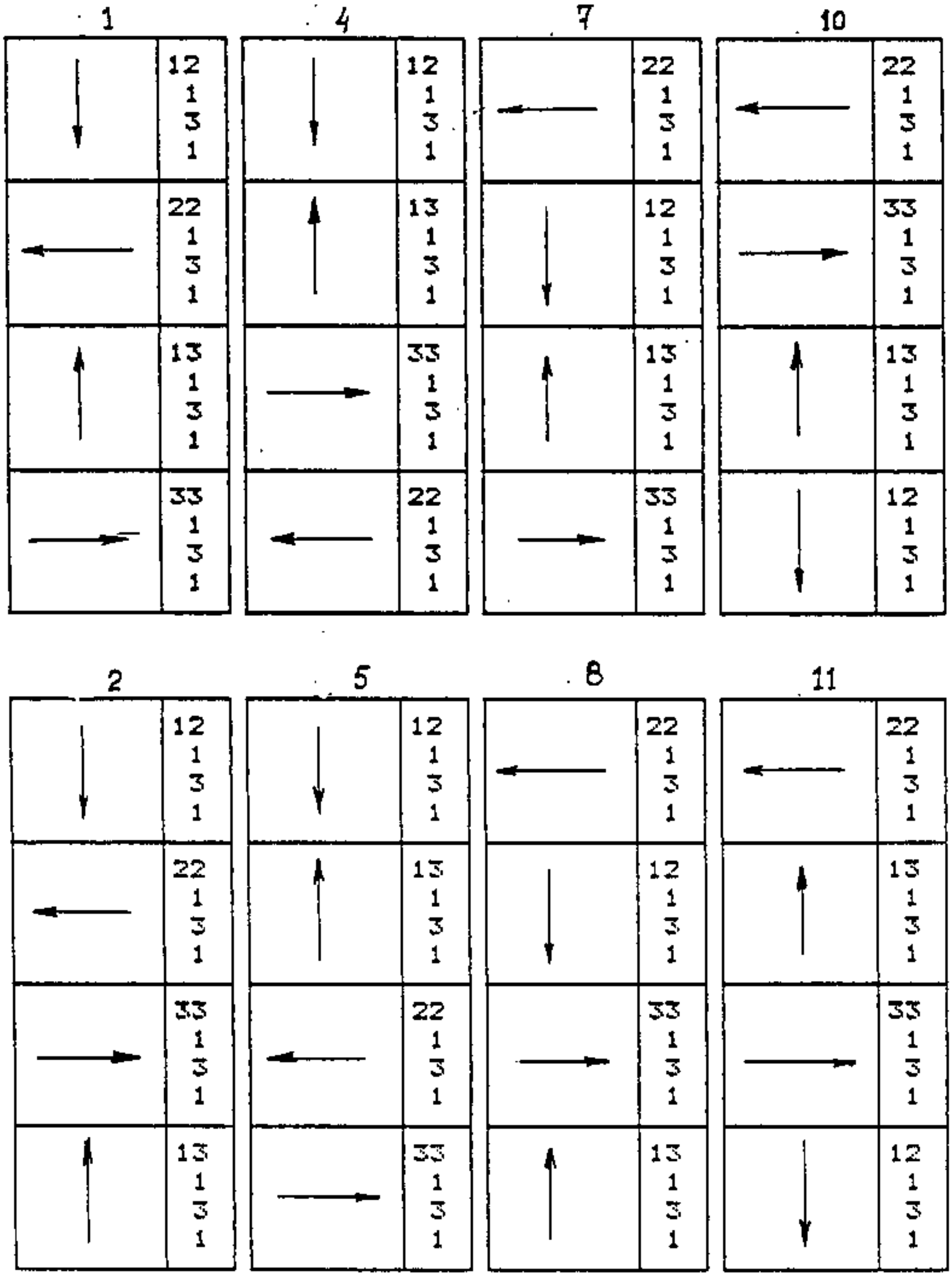
DHV		
R	T	L
5	80	15
28	446	84

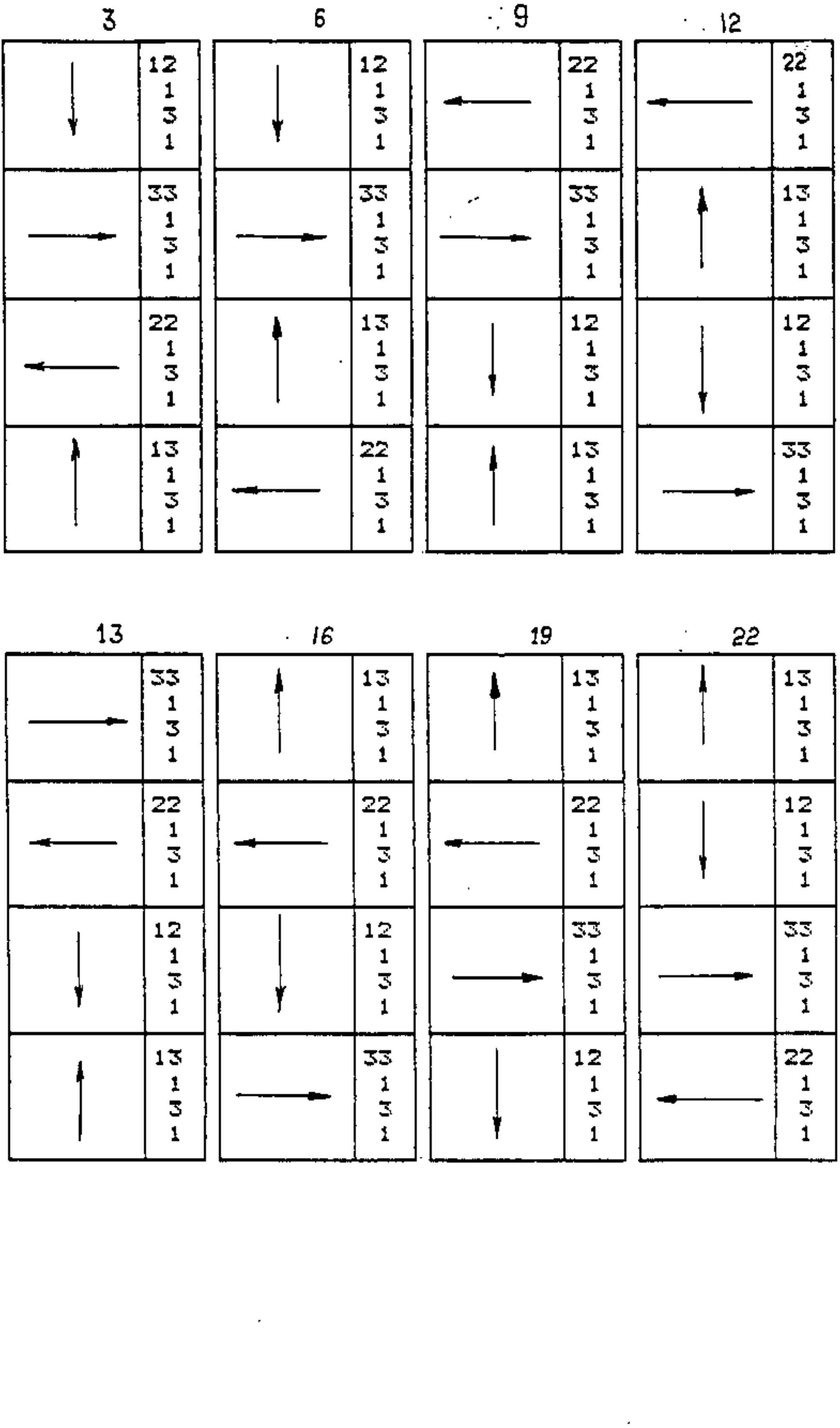
DHV		
R	T	L



Phase sequences:

Node 1




3
12 1 3 1
33 1 3 1
22 1 3 1
13 1 3 1
6
12 1 3 1
33 1 3 1
13 1 3 1
22 1 3 1
9
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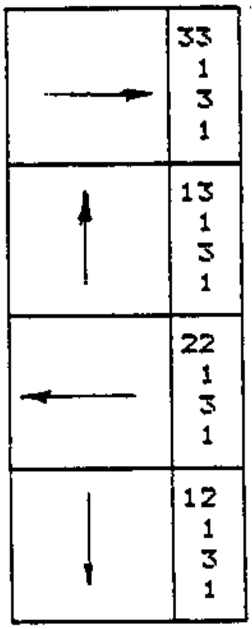
33 1 3 1
12 1 3 1
13 1 3 1
12
22 1 3 1
13 1 3 1
12 1 3 1
33 1 3 1
13
33 1 3 1
22 1 3 1
12 1 3 1
13 1 3 1
16
13 1 3 1
22 1 3 1
12 1 3 1
33 1 3 1
19
13 1 3 1
22 1 3 1
33 1 3 1
12 1 3 1
22
13 1 3 1
12 1 3 1
33 1 3 1
22 1 3 1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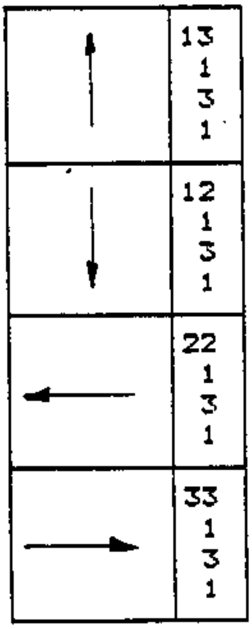
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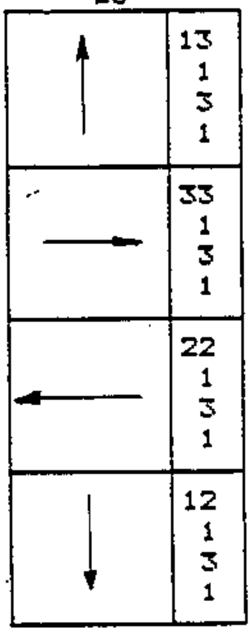
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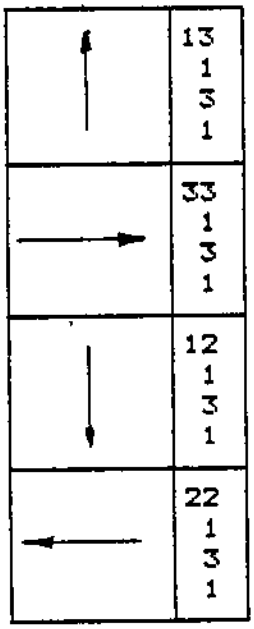
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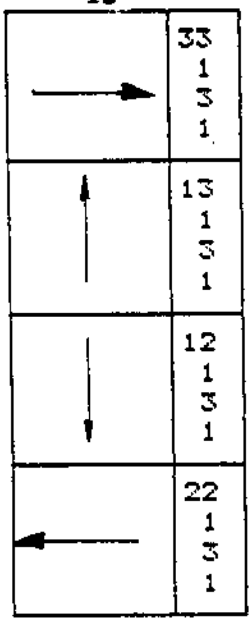
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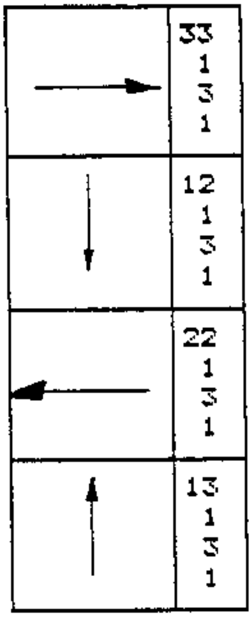
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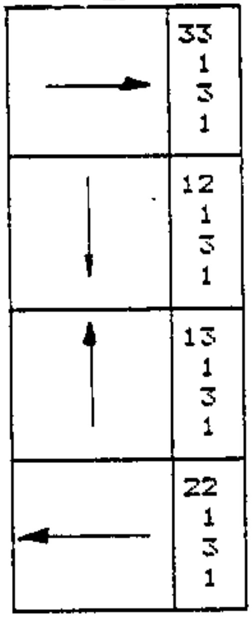
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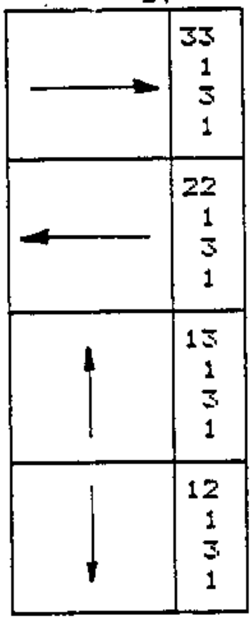
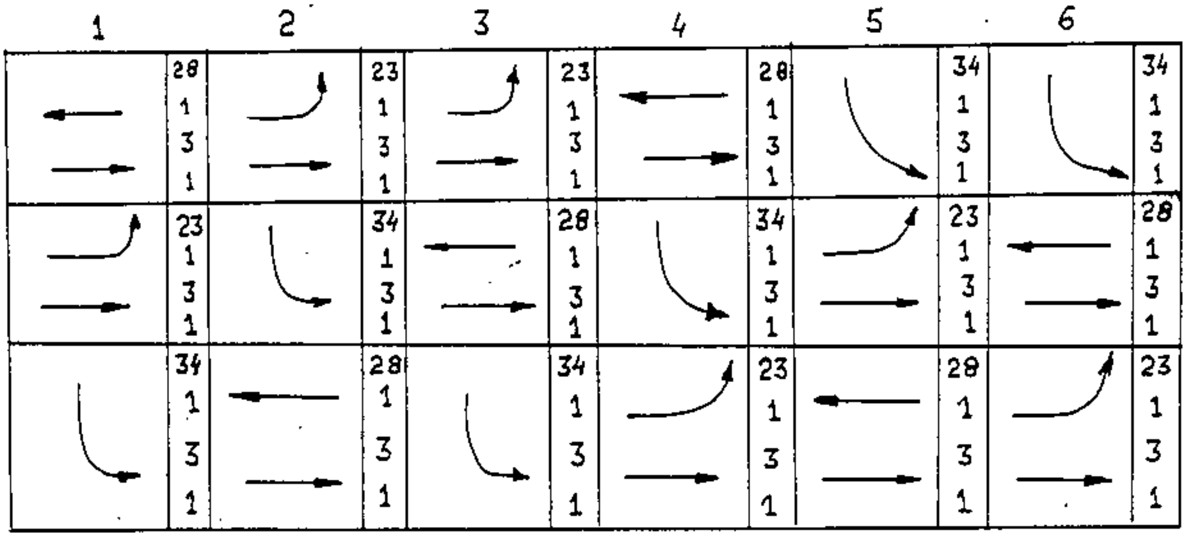
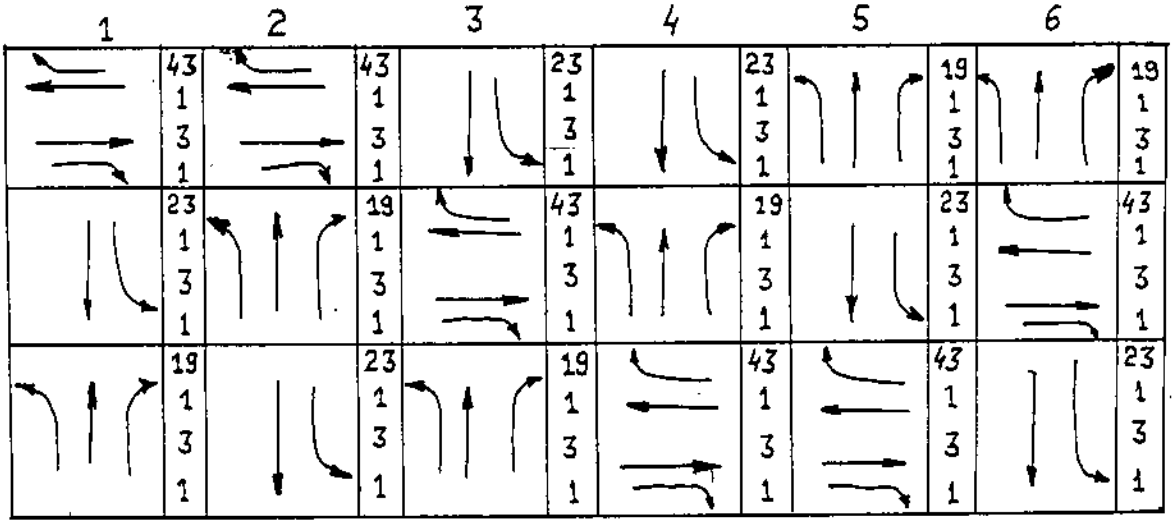

24

Node 2


1
2
3
4
5
6
28 1 3 1
23 1 3 1
23 1 3 1
28 1 3 1
34 1 3 1
34 1 3 1
23 1 3 1
34 1 3 1
28 1 3 1
34 1 3 1
23 1 3 1
28 1 3 1
34 1 3 1
28 1 3 1
34 1 3 1
23 1 3 1
28 1 3 1
23 1 3 1

Node 3


1
2
3
4
5
6
43 1 3 1
43 1 3 1
23 1 3 1
23 1 3 1
19 1 3 1
19 1 3 1
23 1 3 1
19 1 3 1
43 1 3 1
19 1 3 1
23 1 3 1
43 1 3 1
19 1 3 1
23 1 3 1
19 1 3 1
43 1 3 1
43 1 3 1
23 1 3 1

APPENDIX F

COMPLETE SAMPLE OUTPUT

```
1        T R A N S Y T - 7 F  --  T R A F F I C   S I G N A L   S Y S T E M   O P T I M I Z A T I O N   P R O G R A M
 RELEASE 6  OCTOBER 1988                                                                                       VERSION 3.0

 SPONSORED BY:                                                                                              DEVELOPED BY:
 FEDERAL HIGHWAY ADMINISTRATION                                                   TRANSPORT AND ROAD RESEARCH LABORATORY
 OFFICE OF TRAFFIC OPERATIONS                                                                       UNITED KINGDOM AND
                                                                                          TRANSPORTATION RESEARCH CENTER
                                                                                                   UNIVERSITY OF FLORIDA

 DATE OF RUN: 12/26/90  START TIME OF RUN:   13:11:13
                                         -----------------------------------------------
                                         I N P U T   D A T A   R E P O R T   F O R   R U N   1
                                         -----------------------------------------------

 FIELDS:  1     2     3     4     5     6     7     8     9    10    11    12    13    14    15    16
         ----  ----  ----  ----  ----  ----  ----  ----  ----  ----  ----  ----  ----  ----  ----  ----
 LINE                                                     RUN  TITLE  CARD
  NO.    TITLE

  1)      PRINCE SHAKER STREET
                                                  NETWORK  CONTROL  CARD
                                     SEC/  SEC/
 LINE   CARD   MIN    MAX   CYCLE   STEP  STEP   LOST   GREEN   STOP  OUTPUT INITIAL PERIOD SEC(0) SPD(0) ENGL(0) PNCH
 NO.    TYPE  CYCLE  CYCLE  INCR.   CYCLE NORMAL TIME   EXTEN. PENALTY LEVEL TIMINGS LENGTH PERC(1) TIME(1) METR(1) DECK

  2)     1     90    125     5       3     1      3      3     -1      0      0      30     0      0      1      0

 +++ 106 +++ WARNING +
 +                          THE SEC/STEPS FACTOR IN FIELD 6 IS TOO SMALL FOR CYCLE
                            LENGTHS ABOVE  60 SECONDS. IT WILL BE INCREASED TO
                            ALLOW A MAXIMUM OF 60 STEPS/CYCLE.

 +++ 107 +++ WARNING +
 +                          A STOP PENALTY OF "-1" WILL RESULT IN AUTOMATIC
                            CALCULATION OF THE PI TO MINIMIZE FUEL CONSUMPTION.
                            LINK SPECIFIC DELAY OR STOP WEIGHTS ON CARD
                            TYPE 37 & 38 WILL STILL BE APPLIED, HOWEVER.

 +++ 114 +++ WARNING +
 +                          INITIAL TIMING FLAG SET TO "1" FOR CYCLE RANGE EVALUATION.

 LINE   CARD                                      LIST  OF  NODES  TO  BE  OPTIMIZED
  NO.   TYPE

  3)     2     1     2     3     0     0     0     0     0     0     0     0     0     0     0     0

                                                  LINKS  HAVING  SHARED  STOPLINES
 LINE   CARD     FIRST SET..........................     SECOND SET..........................     THIRD SET........................
  NO.   TYPE
```

```
1TRANSYT-7F: PRINCE SHAKER STREET                                                                                    PAGE  2

FIELDS:  1        2        3        4        5        6        7        8        9       10       11       12       13       14       15       16
       ----     ----     ----     ----     ----     ----     ----     ----     ----     ----     ----     ----     ----     ----     ----     ----
  4)      7      107      108      109        0        0      110      111      112        0        0      101      102      103        0        0
  5)      7      104      105      106        0        0      307      308        0        0        0      309      310        0        0        0
  6)      7      301      303        0        0        0      304      305   |  306        0        0        0        0        0        0        0

                                                                 SYSTEM  MASTER  DATA
LINE     CARD     MASTER   SYSTEM DEFAULTS SYSTEM  EXTERNAL SYSTEM  FUEL    VEHICLE ORIEN- DESIRED % OF SAT  MBQ      INFLAT   FUEL VEHICLE
 NO.     TYPE      NODE    YELLOW  ALL-RED SATFLOW  SPEED     PDF   FACTOR  LENGTH  TATION  SPLITS  2-CYC   WEIGHT    RATE    COST    OCC.

  7)      10        0        4        1     1800      35       50       0        0        0        0        0        0       75      100       0

--- PROGRAM NOTE --- NON-DEFAULT INPUT UNITS WERE SPECIFIED AS FOLLOWS:

                   * ENGLISH/METRIC UNITS IN METRIC


-----------------
INTERSECTION     1
-----------------
                                                              CONTROLLER  TIMING  DATA
LINE     CARD     NODE  OFFSET/              INTERVAL DURATIONS (SECS. OR PERCENT) ............................................ DOUBLE
 NO.     TYPE      NO.  YLD.PT.   REF INT   INT1     INT2     INT3     INT4     INT5     INT6     INT7     INT8   . INT9     INT10    INT11  CYCLE

  8)      14        1       0        1       12        1        3        1       22        1        3        1       33        1        3       0

                                                          CONTROLLER  TIMING  DATA  (CONTINUED)
LINE     CARD     NODE     INTERVAL DURATIONS (SECS. OR PERCENT) .......................................................................
 NO.     TYPE      NO.     INT12    INT13    INT14    INT15    INT16    INT17    INT18    INT19    INT20    INT21    INT22    INT23    INT24  INT25

  9)      18        1        1       13        1        3        1        0        0        0        0        0        0        0        0       0

                                                              PHASE  TIMING  DATA
LINE     CARD     NODE     START   VARIAB.  YELLOW   ALL-RED  MINIM.                                                                     PHASE
 NO.     TYPE      NO.     INTVL    INTVL    INTVL    INTVL    SECS.   LINKS MOVING IN THIS PHASE .................................   TYPE

 10)      21        1        1        1        2        4       14      101      102      103        0        0        0        0        0       0
 11)      22        1        5        5        6        8       15      110      111      112        0        0        0        0        0       0
 12)      23        1        9        9       10       12       28      107      108      109        0        0        0        0        0       0
 13)      24        1       13       13       14       16       15      104      105      106        0        0        0        0        0       0

                                                                    LINK  DATA
LINE     CARD     LINK    LINK      SAT.    TOTAL   MID-BLK. FIRST INPUT LINK....     SECOND INPUT LINK....     THIRD INPUT LINK....  QUEUE
 NO.     TYPE      NO.   LENGTH     FLOW     VOL.     VOL.     NO.     VOL.   SPD/TT     NO.     VOL.   SPD/TT     NO.     VOL.   SPD/TT  CAP.

 14)      28      101     200     1900       10        0        0        0       35        0        0        0        0        0        0       0
 15)      28      102     200        0      130        0        0        0       35        0        0        0        0        0        0       0
 16)      28      103     200        0       96        0        0        0       35        0        0        0        0        0        0       0
 17)      20      104     200     1880       66        0        0        0       35        0        0        0        0        0        0       0
 18)      28      105     200        0       50        0        0        0       35        0        0        0        0        0        0       0
 19)      20      106     200        0      264        0        0        0       35        0        0        0        0        0        0       0
 20)      28      107     400     1950      844        0        0        0       35        0        0        0        0        0        0       0
 21)      28      108     400        0       38        0        0        0       35        0        0        0        0        0        0       0
```

```
1TRANSYT-7F: PRINCE SHAKER STREET                                                                                PAGE  3

FIELDS:   1       2       3       4       5       6       7       8       9      10      11      12      13      14      15      16
       ----    ----    ----    ----    ----    ----    ----    ----    ----    ----    ----    ----    ----    ----    ----    ----
 22)     28     109     400       0     270       0       0       0      35       0       0       0       0       0       0       0
 23)     28     110     426    2250     540       0     206     446      35     202     100      40       0       0       0       0
 24)     28     111     426       0      34       0     206      28      35       0       0       0       0       0       0       0
 25)     28     112     426       0     168       0     206      84      35       0       0       0       0       0       0       0

-----------------
INTERSECTION    2
-----------------

                                                   CONTROLLER  TIMING  DATA
LINE   CARD    NODE OFFSET/         INTERVAL DURATIONS (SECS. OR PERCENT) .............................................. DOUBLE
 NO.   TYPE     NO. VLD.PT. REF INT    INT1    INT2    INT3    INT4    INT5    INT6    INT7    INT8    INT9   INT10   INT11   CYCLE

 26)     13       2       0       1      28       1       3       1      23       1       3       1      34       1       3       0

                                              CONTROLLER  TIMING  DATA  (CONTINUED)
LINE   CARD    NODE   INTERVAL DURATIONS (SECS. OR PERCENT) ...........................................................
 NO.   TYPE     NO.   INT12   INT13   INT14   INT15   INT16   INT17   INT18   INT19   INT20   INT21   INT22   INT23   INT24   INT25

 27)     18       2       1       0       0       0       0       0       0       0       0       0       0       0       0       0

                                                     PHASE  TIMING  DATA
LINE   CARD    NODE   START VARIAB.  YELLOW ALL-RED  MINIM.                                                            PHASE
 NO.   TYPE     NO.   INTVL   INTVL   INTVL   INTVL   SECS.   LINKS MOVING IN THIS PHASE ................................  TYPE

 28)     21       2       1       1       2       4      24     204     206     202     207       0       0       0       0       0
 29)     22       2       5       5       6       8      20     204     205     202     207       0       0       0       0       0
 30)     23       2       9       9      10      12      28     201     202     207       0       0       0       0       0       0

                                                           LINK  DATA
LINE   CARD    LINK    LINK    SAT.   TOTAL MID-BLK. FIRST INPUT LINK....    SECOND INPUT LINK....   THIRD INPUT LINK....   QUEUE
 NO.   TYPE     NO.  LENGTH    FLOW    VOL.    VOL.     NO.    VOL.  SPD/TT     NO.    VOL.  SPD/TT     NO.    VOL.  SPD/TT    CAP.

 31)     28     201     400    2420     850       0       0       0      35       0       0       0       0       0       0       0
 32)     28     202     400    1200     100       0       0       0      35       0       0       0       0       0       0       0
 33)     28     204     426    2075     884       0     107     591      35     103      96      40     105      50      40       0
 34)     28     205     426    1100     376       0     107     253      35       0       0       0       0       0       0       0
 35)     28     206     177    2215     558       0     309     598      35     302     250      40     306      56      40       0
 36)     28     207     177    1200     256       0     309     256      35       0       0       0       0       0       0       0

-----------------
INTERSECTION    3
-----------------

                                                   CONTROLLER  TIMING  DATA
LINE   CARD    NODE OFFSET/         INTERVAL DURATIONS (SECS. OR PERCENT) .............................................. DOUBLE
 NO.   TYPE     NO. VLD.PT. REF INT    INT1    INT2    INT3    INT4    INT5    INT6    INT7    INT8    INT9   INT10   INT11   CYCLE

 37)     13       3       0       1      23       1       3       1      43       1       3       1      19       1       3       0
```

```
                                                                                                                         PAGE  4
1TRANSYT-7F: PRINCE SHAKER STREET

FIELDS:  1       2       3       4       5       6       7       8       9       10      11      12      13      14      15      16
        ----    ----    ----    ----    ----    ----    ----    ----    ----    ----    ----    ----    ----    ----    ----    ----

                                                        CONTROLLER  TIMING  DATA  (CONTINUED)
LINE    CARD    NODE    INTERVAL DURATIONS (SECS. OR PERCENT) ...........................................................
 NO.    TYPE     NO.    INT12   INT13   INT14   INT15   INT16   INT17   INT18   INT19   INT20   INT21   INT22   INT23   INT24   INT25

 38)     18       3       1       0       0       0       0       0       0       0       0       0       0       0       0       0

                                                       PHASE  TIMING  DATA
LINE    CARD    NODE    START   VARIAB. YELLOW  ALL-RED MINIM.                                                                PHASE
 NO.    TYPE     NO.    INTVL   INTVL   INTVL   INTVL   SECS.   LINKS MOVING IN THIS PHASE ...............................    TYPE

 39)     21       3       1       1       2       4      21     301     302     303       0       0       0       0       0       0
 40)     22       3       5       5       6       8      34     307     308     309     310     302       0       0       0       0
 41)     23       3       9       9      10      12      19     304     305     306     302       0       0       0       0       0

                                                              LINK  DATA
LINE    CARD    LINK    LINK     SAT.   TOTAL   MID-BLK. FIRST INPUT LINK....    SECOND INPUT LINK....    THIRD INPUT LINK....   QUEUE
 NO.    TYPE     NO.   LENGTH    FLOW    VOL.    VOL.     NO.     VOL.   SPD/TT    NO.     VOL.   SPD/TT    NO.     VOL.   SPD/TT   CAP.

 42)     28     301     300     1950     160       0       0       0      35       0       0       0       0       0       0       0
 43)     28     302     300     1200     250       0       0       0      35       0       0       0       0       0       0       0
 44)     28     303     300        0     464       0       0       0      35       0       0       0       0       0       0       0
 45)     28     304     600     1100     226       0       0       0      35       0       0       0       0       0       0       0
 46)     28     305     600        0     112       0       0       0      35       0       0       0       0       0       0       0
 47)     28     306     600        0      56       0       0       0      35       0       0       0       0       0       0       0
 48)     28     307     177     2150    1358       0     204     776      35     201     850      40       0       0       0       0
 49)     28     308     177        0     108       0     204      68      35       0       0       0       0       0       0       0
 50)     28     309     300     2150     854       0       0       0      35       0       0       0       0       0       0       0
 51)     28     310     300        0      96       0       0       0      35       0       0       0       0       0       0       0

                                                            RUN  CARD
LINE    CARD     PI
 NO.    TYPE    TYPE

 52)     53       0       0       0       0       0       0       0       0       0       0       0       0       0       0       0

--- PROGRAM NOTE --- A CARD TYPE 53 CAUSES RUN TO BE OPTIMIZED USING THE
                     DEFAULT QUICK OPTIMIZATION STEP SIZES.
                     IF CARD TYPE 4 WAS INPUT, IT IS IGNORED.

                     THE ABOVE WILL BE PROCESSED AFTER THE "BEST" CYCLE
                     LENGTH HAS BEEN SELECTED.

--- PROGRAM NOTE --- NO ERRORS DETECTED. TRANSYT-7F PERFORMS FINAL PROCESSING.
                     IF ERRORS ARE DETECTED, FURTHER PROCESSING IS SUSPENDED.

--- PROGRAM NOTE --- THERE ARE A TOTAL OF   3 NODES AND  28 LINKS,
                     INCLUDING BOTTLENECKS, IF ANY, IN THIS RUN.

--- PROGRAM NOTE --- THERE WERE A TOTAL OF   3 WARNING MESSAGES ISSUED
                     IN THE ABOVE REPORT.
```

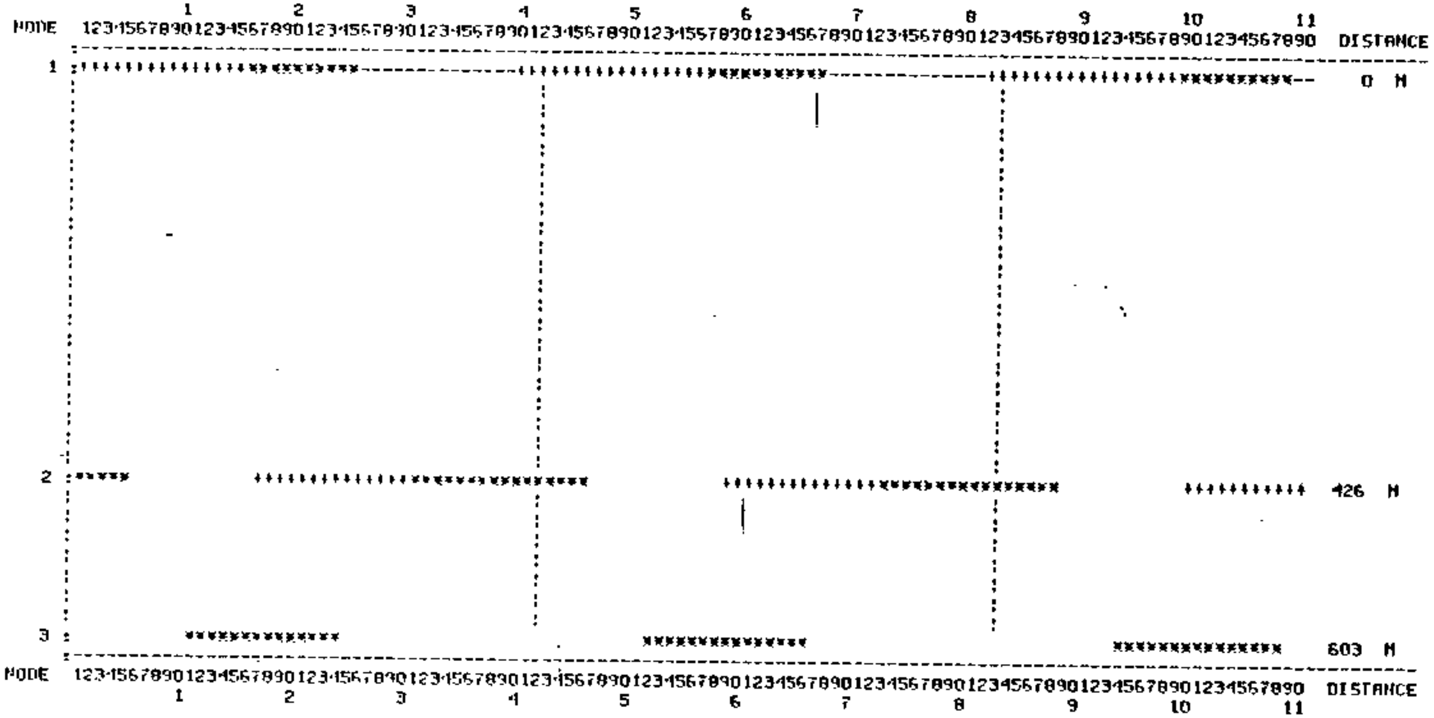
```
                    -----------------------------------
                    CYCLE EVALUATION SUMMARY PERFORMANCE
                    -----------------------------------

 CYCLE    STEP    AVERAGE   PERCENT      FUEL      PERFORMANCE  NUMBER
LENGTH    SIZE     DELAY     STOPS    CONSUMPTION     INDEX    SATURATED
 (SEC)  (STEPS)  (SEC/VEH)    (%)       (GAL/HR)                 LINKS
-----------------------------------------------------------------------

   90      30     181.94      63       1704.1        361.0         22

   95      32     177.83      62       1673.5        352.9         22

  100      33     177.22      60       1666.8        351.1         22

  105      35     173.61      54       1635.1        342.7         21

  110      37     172.85      55       1630.5        341.5         21

  115      38     172.05      53       1622.1        339.3         22

  120      40     171.88      54       1622.1        339.3         21

  125      42     170.65      54       1613.4        337.0         21

-----------------------------------------------------------------------

    BEST CYCLE LENGTH = 125 SEC.   CYCLE SENSITIVITY =   2.4 %

--- PROGRAM NOTE --- TRANSYT-7F OPTIMIZES THE SYSTEM USING THE BEST
                     CYCLE LENGTH AND HILL-CLIMB STEP SIZES AS
                     INDICATED BY CARD TYPE 53.
```

```
1 PRINCE SHAKER STREET                                                                        CYCLE:  125 SECONDS,   60 STEPS   PAGE  6

 <PERFORMANCE WITH OPTIMAL SETTINGS>

   NODE LINK   FLOW    SAT  DEGREE  TOTAL      TOTAL   -------- DELAY --------  AVERAGE   UNIFORM   MAX BACK  QUEUE     FUEL  PHASE  LINK
    NO.  NO.          FLOW  OF SAT  TRAVEL     TIME    UNIFORM  RANDOM   TOTAL   DELAY     STOPS    OF QUEUE CAPACITY  CONSUM LENGTH  NO.
              (VEH/H)(VEH/H) (%)  (VEH-KM/H)(VEH-H/H)          (VEH-H/H)       (SEC/VEH) (VEH/H;%) (VEH/LK)(VEH/LK)  (LI/H) (SEC)

     1   101      10  1900P  150*     2.00      1.11      .20      .85    1.05  378.0      6.7( 67%)   14         26    3.34     15   101
     1   102     130   1015  150*    38.00     21.08     3.89    16.10   19.99  379.8    126.8( 67%)  101       1015   61.09     15   102
     1   103      96   1015  150*    19.20     10.65     1.37     8.13   10.10  379.8     64.1( 67%)  101       1015   30.87     15   103
     1   104      66  1880P  168*    13.20      8.66     1.52     6.77    8.29  452.1     39.2( 59%)   20         26   24.89     17   104
     1   105      50   1045  168*    10.00      6.56     1.15     5.13    6.28  452.1     29.7( 59%)  104       1045   18.86     17   105
     1   105     264   1045  168*    52.80     34.66     6.09    27.07   33.15  452.1    156.7( 59%)  104       1045   99.57     17   106
     1   107     844  1950P  151*   337.60     98.27    17.27    71.35   88.62  378.0    560.0( 66%)   66  >     53C  289.84     51   107
     1   109      38   1075  151*    15.20      4.42      .78     3.21    3.99  378.0     25.2( 66%)  107       1075   13.05     51   108
     1   109     270   1075  151*   108.00     31.44     5.53    22.83   28.35  378.0    179.2( 66%)  107       1075   92.72     51   109
     1   110     540  2250P  103*   230.04     17.19     3.60     7.17   10.77   71.8    511.9( 95%)   25         56   61.37     42   110
     1   111      34   1105  103*    14.48      1.06      .20      .45     .65   68.8     31.6( 93%)  110       1105    3.78     42   111
     1   112     168   1105  103*    71.57      5.27     1.00     2.23    3.23   69.1    159.2( 95%)  110       1105   18.75     42   112

     1 :        2570   MAX = 168*   912.09    240.38    43.13   171.28  214.47  300.4   1890.2( 74%)                    718.14 PI =  162.6

     2   201     850  2420    95*   340.00     22.20     8.91     3.57   12.48   52.9    790.8( 93%)   29         53   81.57     48   201
     2   202     100  1200     8     40.00      1.14      .00      .00     .00     .0       .0(  0%)    0         53    4.50    125   202
     2   204     884  2075    71    376.58     12.62     1.70      .43    2.13    8.7    167.2( 19%)    6         56   49.77     77   204
     2   205     376  1100   104*   160.18     12.47     1.03     6.87    7.89   75.5    134.3( 36%)    6         56   41.38     43   205
     2   206     558  2215    90*    98.77     12.82     5.48     4.64   10.12   65.3    510.9( 92%)   18         23   45.10     34   206
     2   207     256  1200    21     45.31      1.29      .00      .00     .00     .0       .0(  0%)    0         23    5.10    125   207

     2 :        3024   MAX = 104*  1060.84     62.55    17.11    15.51   32.63   38.8   1603.2( 53%)                    227.41 PI =   28.7

     3   301     160  1350P  182*    48.00     23.23     3.78    18.08   21.86  491.9     88.0( 55%)   43  >     39C   66.98     24   301
     3   302     250  1200    21     75.00      2.14      .00      .00     .00     .0       .0(  0%)    0         39    8.44    125   302
     3   303     464   3015  182*   139.20     57.37    10.97    52.42   63.40  491.9    255.2( 55%)  301       3015  194.23     24   303
     3   304     226  1100P  249*   135.60     44.31     6.55    33.88   40.43  644.0     90.9( 40%)   22         79  128.35     20   304
     3   305     112   3045  249*    67.20     21.96     3.25    16.79   20.04  644.0     45.0( 40%)  304       3045   63.61     20   305
     3   306      56   3045  249*    33.60     10.98     1.62     8.40   10.02  644.0     22.5( 40%)  304       3045   31.80     20   306
     3   307    1358  2150P  108*   240.37     36.76     2.90    27.44   30.34   80.4    400.0( 29%)   17         23  115.41     81   307
     3   308     108   3075  108*    19.12      3.11      .38     2.18    2.57   85.5     58.0( 54%)  307       3075    9.90     81   308
     3   309     854  2150P   70    256.20     11.12     3.43      .36    3.80   16.0    515.8( 60%)   21         39   45.03     81   309
     3   310      96   3095   70     28.80      1.25      .39      .04     .43   16.0     58.0( 60%)  309       3095    5.06     81   310

     3 :        3684   MAX = 249*  1043.00    222.22    33.28   159.59  192.87  188.5   1533.4( 42%)                    668.80 PI =  145.9
```

```
1 PRINCE SHAKER STREET                                                          CYCLE:  125 SECONDS,   60 STEPS   PAGE  7

                                       <SYSTEM WIDE TOTALS INCLUDING ALL LINKS>

   TOTAL       TOTAL     TOTAL     TOTAL     TOTAL    AVERAGE      TOTAL       TOTAL
  DISTANCE     TRAVEL   UNIFORM    RANDOM    DELAY     DELAY      UNIFORM       FUEL    OPERATING PERFORMANCE  SPEED
  TRAVELED      TIME     DELAY     DELAY                           STOPS       CONSUM      COST      INDEX
 (VEH-KM/H) (VEH-H/H) (VEH-H/H) (VEH-H/H) (VEH-H/H) (SEC/VEH)   (VEH/H-2)     (LI/H)                            (KM/H)

   3016.01    525.15     93.58    346.38    433.97    170.71   5026.8( 542)  1614.35    2095.22    337.22       5.74 <TOTALS>
NOTE: PERFORMANCE INDEX IS DEFINED AS:

      PI = DELAY + STOPS

NO. OF SIMULATIONS =  17  NO. OF LINKS = 266  ELAPSED TIME =  2389.0 SEC.
```

```
1 PRINCE SHAKER STREET                                                                CYCLE:  125 SECONDS.   60 STEPS   PAGE  8

 --- PROGRAM NOTE ---INPUT DATA REPORT FOR ROUTE REQUEST NO.   1

                                                                ROUTE  SUMMARY  DATA
 LINE    CARD    TSD     TIME     TIME     DIST.    PPD   ROUTE    PPD    GOF                                                      ROUTE
  NO.    TYPE    FLAG    FLAG     SCALE    SCALE    FLAG  SUMMARY  FLAG   FLAG                                                     ORIENT.

  530     60      1       1        0        0        1      1       1      1      0      0      0      0      0      0      0

 LINE
  NO.    TITLE                                                  ROUTE  TITLE  CARD

  540       THE TSD ORIENTATION DOWNBOUND ON THE PAGE IS WESTBOUND

                                                                ROUTE  LINK  LIST
 LINE    CARD    LINK PAIRS ALTERNATING BY DIRECTION
  NO.    TYPE    DOWN AND UP      DOWN AND UP      DOWN AND UP      DOWN AND UP      DOWN AND UP      DOWN AND UP      DOWN AND UP

  550     61     107     110      204     206      307     309       0      0      0      0      0      0      0      0      0
```

```
1 PRINCE SHAKER STREET                                                        CYCLE:  125 SECONDS,   60 STEPS   PAGE  9

                          < T R A N S Y T - 7 F   T I M E - S P A C E   D I A G R A M >

                    ROUTE NO.  1  ROUTE TITLE:    THE TSD ORIENTATION DOWNBOUND ON THE PAGE IS WESTBOUND

                    TIME AXIS IS IN: SEC          TIME SCALE =   3 SEC/CHAR,  DIST. SCALE =   20  M/LINE
```



```
SCALE CONVERSIONS:                            +++ GREEN IN DOWN DIRECTION           AVG. TIME DISPLACEMENT:
TIME/INCH =  3 * 10 (AT 10 CHAR/INCH)             GREEN IN BOTH DIRECTIONS            723.60 / SPEED
DIST/INCH =  20 * 6 (AT 6 LINES/INCH)         --- GREEN IN UP   DIRECTION
                                              *** RED   IN BOTH DIRECTIONS
```

```
                                                                                    CYCLE:  125 SECONDS.    60 STEPS    PAGE 10
1 PRINCE SHAKER STREET
                              < T R A N S Y T - 7 F   F L O W   P R O F I L E   D I A G R A M S >

ROUTE TITLE:    THE TSD ORIENTATION DOWNBOUND ON THE PAGE IS WESTBOUND


SYMBOL KEYS:

   FLOW PROFILE SYMBOLS (VERTICAL AXIS IS IN VPH).
       I :  ARRIVALS WHICH QUEUE, NORMALLY ON RED ON UNOPPOSED LINKS OR
            DURING PERIODS OF HEAVY OPPOSING FLOW ON OPPOSED LINKS DURING
            THE PERMITTED PHASE(S).
       S :  DEPARTURES FROM QUEUE. NORMALLY AT THE SATURATION FLOW RATE
            FOR "PROTECTED" LINKS. OR MAXIMUM FLOW RATE FOR PERMITTED,
            OPPOSED LINKS.
       O :  ARRIVALS AND DEPARTURES ON GREEN. WHEN BELOW S'S OR I'S, THESE
            ARRIVALS JOIN THE BACK OF THE QUEUE.


    TIME SCALE (VERTICAL AXIS):
  (BLANK) :  PROTECTED GREEN INTERVALS OR UNOPPOSED MOVEMENTS.
        . :  PERMITTED GREEN INTERVALS WITH OPPOSING TRAFFIC.
        * :  RED INTERVALS.
        N :  THE NUMBERS ACROSS THE BOTTOM ARE A TIME SCALE IN
             UNITS OF STEPS.

NOTE: THE FLOW PROFILE DIAGRAM SHOWS EFFECTIVE GREEN AND RED, NOT ACTUAL.
      OFFSETS ARE NOT ADJUSTED TO MASTER CONTROLLER IF ANY.
```

```
  THE TSD ORIENTATION DOWNBOUND ON THE PAGE IS WESTBOUND                      CYCLE:  125 SECONDS.   60 STEPS   PAGE 11

    LINK   107    MAX FLOW  1423 VEH/H     PLT. INDEX  .00

2000+
    :
    :
    :
    :
    :
1500+
    :SSSSSSSSSSSSSSSSSSSSS                                     SS
    :SSSSSSSSSSSSSSSSSSSSS                                     SS
    :SSSSSSSSSSSSSSSSSSSSS                                     SS
    :SSSSSSSSSSSSSSSSSSSSS                                     SS
    :SSSSSSSSSSSSSSSSSSSSS                                     SS
1000:SSSSSSSSSSSSSSSSSSSSS                                     SS
    :SSSSSSSSSSSSSSSSSSSSS                                     SS
    :OOOOOOOOOOOOOOOOOOOOOIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIOO
    :OOOOOOOOOOOOOOOOOOOOOIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIOO
    :OOOOOOOOOOOOOOOOOOOOOIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIOO
    :OOOOOOOOOOOOOOOOOOOOOIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIOOO
 500+OOOOOOOOOOOOOOOOOOOOOIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIOOO
    :OOOOOOOOOOOOOOOOOOOOOIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIOOO
    :OOOOOOOOOOOOOOOOOOOOOIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIOOO
    :OOOOOOOOOOOOOOOOOOOOOIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIOOO
    :OOOOOOOOOOOOOOOOOOOOOOIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIOOO
    :OOOOOOOOOOOOOOOOOOOOOOIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIOOO
                            ***********************************
      123456789012345678901234567890123456789012345678901234567890

    LINK   110    MAX FLOW  1995 VEH/H     PLT. INDEX  .72

2000+                                       S
    :                                      SS
    :                                      SS
    :                                      SS
    :                                      SS              SS
    :                                      SSSSSSSSSSSSSSSSSS
1500+                                      OSSSSSSSSSSSSSSSSS
    :                                    IIOOSSSSSSSSSSSSSSSS
    :                                   IIIOOOSSSSSSSSSSSSSSS
    :                                  IIIIOOOSSSSSSSSSSSSSSS
    :                                 IIIIIOOOOSSSSSSSSSSSSSS
    :                                IIIIIIOOOOOSSSSSSSSSSSSS
1000+                               IIIIIIIOOOOOOSSSSSSSSSSSSS
    :                              IIIIIIIIOOOOOOOSSSSSSSSSSSS
    :                             IIIIIIIIIOOOOOOOOSSSSSSSSSSS
    :                            IIIIIIIIIIOOOOOOOOOSSSSSSSSSS
    :                            IIIIIIIIIIOOOOOOOOOOSSSSSSSSS
    :                           IIIIIIIIIIIOOOOOOOOOOOOSSSSSSS
 500+                           IIIIIIIIIIIOOOOOOOOOOOOOSSSSSS
    :                          IIIIIIIIIIIIOOOOOOOOOOOOOOOOSSS
    :                          IIIIIIIIIIIIOOOOOOOOOOOOOOOOOOO
    :II                       IIIIIIIIIIIIIOOOOOOOOOOOOOOOOOOOIII
    :IIIIIIIIIIIIIII          IIIIIIIIIIIIIOOOOOOOOOOOOOOOOOOOIII
    :IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIOOOOOOOOOOOOOOOOOOOIII
      *************************************                    ***
      123456789012345678901234567890123456789012345678901234567890

    LINK   204    MAX FLOW  2075 VEH/H     PLT. INDEX  .42

3000+
    :
    :
    :
    :
    :
2250+
    :         SSSS
    :         SSSS
    :         SSSS
    :        SSSSS
    :        SSSSS
1500+        SSSSS
    :        SSSSS
    :        SSSSS
    :        SSSSS                    OOOOOO
    :        SSSSS              OOOOOOOOOOOOO
    :        SSSSS           OOOOOOOOOOOOOOOOOO
 750+        SSSSS        OOOOOOOOOOOOOOOOOOOOOOO  IIIII
    :        SSSSS      OOOOOOOOOOOOOOOOOOOOOOOOOOIIIIIIII
    :        SSSSS     OOOOOOOOOOOOOOOOOOOOOOOOOOOIIIIIIIIII
    :        SSSSS   OOOOOOOOOOOOOOOOOOOOOOOOOOOOOIIIIIIIIIIIII
    :II      SSSSS  OOOOOOOOOOOOOOOOOOOOOOOOOOOOOOIIIIIIIIIIIIIII
    :IIIIIIIOOOSSSOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOIIIIIIIIIIIIIII
      ********                                     ***************
      123456789012345678901234567890123456789012345678901234567890

    LINK   206    MAX FLOW  2215 VEH/H     PLT. INDEX  .39

3000+
    :
    :
    :
    :
    :
2250+         SSSSSSSSSSSSS
    :         SSSSSSSSSSSSS
    :         SSSSSSSSSSSSS
    :        SSSSSSSSSSSSSS
    :        SSSSSSSSSSSSSS
    :        SSSSSSSSSSSSSS
1500+        SSSSSSSSSSSSSS
    :        SSSSSSSSSSSSSS
    :        SSSSSSSSSSSSSS
    :        SSSSSSSSSSSSSSS
    :        SSSSSSSSSSSSSSS                               IIIIII
    :II      SSSSSSSSSSSSSSS                          IIIIIIIIIII
 750+IIII    SSSSSSSSSSSSSSS                        IIIIIIIIIIIII
    :IIIIIIIIOOSSSSSSSSSSSSS                       IIIIIIIIIIIIII
    :IIIIIIIIOOOOOOOOOOOOOOO                      IIIIIIIIIIIIIII
    :IIIIIIIIOOOOOOOOOOOOOOOOIIII                IIIIIIIIIIIIIIII
    :IIIIIIIIOOOOOOOOOOOOOOOOIIIIIIIIIII        IIIIIIIIIIIIIIIII
    :IIIIIIIIOOOOOOOOOOOOOOOOIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
      ********                ************************************
      123456789012345678901234567890123456789012345678901234567890
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!  THE TSD ORIENTATION DOWNBOUND ON THE PAGE IS WESTBOUND                             CYCLE:  125 SECONDS,   60 STEPS   PAGE 12

    LINK   307    MAX FLOW  2020 VEH/H     PLT. INDEX  .42            LINK   309    MAX FLOW  1933 VEH/H     PLT. INDEX  .00

3000+                                                                2000+
    :                                                                    :                                     SSSSSSSSSSSSSSSS
    :                                                                    :                                     SSSSSSSSSSSSSSSS
    :                                                                    :                                     SSSSSSSSSSSSSSSS
    :                                                                    :                                     SSSSSSSSSSSSSSSS
    :                                                                    :                                     SSSSSSSSSSSSSSSS
2250+                                                                1500+                                     SSSSSSSSSSSSSSSS
    :                                                                    :                                     SSSSSSSSSSSSSSSSS
    :00000000000                          S                              :                                     SSSSSSSSSSSSSSSSS
    :000000000000                         SSSSSSSSSSSSS       000        :                                     SSSSSSSSSSSSSSSSS
    :000000000000                         SSSSSSSSSSSSS     00000        :                                     SSSSSSSSSSSSSSSSS
    :0000000000000                        SSSSSSSSSSSSS    000000        :                                     SSSSSSSSSSSSSSSSS
1500+0000000000000                        SSSSSSSSSSSSS   0000000    1000+                                    SSSSSSSSSSSSSSSSSS
    :0000000000000                        SSSSSSSSSSSSS   0000000        :                                    SSSSSSSSSSSSSSSSSS
    :00000000000000   III                 SSSSSSSSSSSSS  00000000        :000000000000000IIIIIIIIIIIIIIIIIIIII000000000000000000000000
    :00000000000000  IIII                SSSSSSSSSSSSSS  00000000        :000000000000000IIIIIIIIIIIIIIIIIIIII000000000000000000000000
    :000000000000000IIIIII               SSSSSSSSSSSSSS 000000000        :000000000000000IIIIIIIIIIIIIIIIIIIII000000000000000000000000
    :000000000000000IIIIII               SSSSSSSSSSSSSSS000000000        :000000000000000IIIIIIIIIIIIIIIIIIIII000000000000000000000000
 750+000000000000000IIIIIII              SS000000000000S000000000     500+000000000000000IIIIIIIIIIIIIIIIIIIII000000000000000000000000
    :000000000000000IIIIIIII          III000000000000000000000000        :000000000000000IIIIIIIIIIIIIIIIIIIII000000000000000000000000
    :000000000000000IIIIIIIIIIIIIIIIIIIII000000000000000000000000        :000000000000000IIIIIIIIIIIIIIIIIIIII000000000000000000000000
    :000000000000000IIIIIIIIIIIIIIIIIIIII000000000000000000000000        :000000000000000IIIIIIIIIIIIIIIIIIIII000000000000000000000000
    :000000000000000IIIIIIIIIIIIIIIIIIIII000000000000000000000000        :000000000000000IIIIIIIIIIIIIIIIIIIII000000000000000000000000
    :000000000000000IIIIIIIIIIIIIIIIIIIII000000000000000000000000        :000000000000000IIIIIIIIIIIIIIIIIIIII000000000000000000000000
                    *********************                                                ********************* 
     123456789012345678901234567890123456789012345678901234567890         123456789012345678901234567890123456789012345678901234567890
```

```
1 PRINCE SHAKER STREET                                                     CYCLE:  125 SECONDS,   60 STEPS   PAGE 13

  SYMBOL KEYS:

     FLOW PROFILE SYMBOLS (VERTICAL AXIS IS IN VEH).
         I :  ARRIVALS WHICH QUEUE, NORMALLY ON RED ON UNOPPOSED LINKS OR
              DURING PERIODS OF HEAVY OPPOSING FLOW ON OPPOSED LINKS DURING
              THE PERMITTED PHASE(S).
         S :  DEPARTURES FROM QUEUE. NORMALLY AT THE SATURATION FLOW RATE
              FOR "PROTECTED" LINKS, OR MAXIMUM FLOW RATE FOR PERMITTED,
              OPPOSED LINKS.
         O :  ARRIVALS AND DEPARTURES ON GREEN. WHEN BELOW S'S OR I'S, THESE
              ARRIVALS JOIN THE BACK OF THE QUEUE.


     TIME SCALE (VERTICAL AXIS):
   (BLANK) :  PROTECTED GREEN INTERVALS OR UNOPPOSED MOVEMENTS.
         . :  PERMITTED GREEN INTERVALS WITH OPPOSING TRAFFIC.
         * :  RED INTERVALS.
         N :  THE NUMBERS ACROSS THE BOTTOM ARE A TIME SCALE IN
              UNITS OF STEPS.

NOTE: THE FLOW PROFILE DIAGRAM SHOWS EFFECTIVE GREEN AND RED, NOT ACTUAL.
      OFFSETS ARE NOT ADJUSTED TO MASTER CONTROLLER IF ANY.
```

```
1 PRINCE SHAKER STREET                                                        CYCLE:  125 SECONDS,   60 STEPS   PAGE 14

<ROUTE SUMMARY REPORT>    THE TSD ORIENTATION DOWNBOUND ON THE PAGE IS WESTBOUND

  NODE LINK   FLOW    SAT  DEGREE  TOTAL      TOTAL  -------- DELAY --------  AVERAGE   UNIFORM   MAX BACK  QUEUE     FUEL  PHASE  LINK
  NO.  NO.           FLOW  OF SAT  TRAVEL     TIME   UNIFORM  RANDOM   TOTAL   DELAY     STOPS    OF QUEUE CAPACITY CONSUM LENGTH  NO
            (VEH/H)(VEH/H)  (%)  (VEH-KM/H)(VEH-H/H)       (VEH-H/H)         (SEC/VEH) (VEH/H;%) (VEH/LK)(VEH/LK)  (LI/H)  (SEC)

    1   107    844  1950P  151*   337.60     98.27    17.27    71.35   89.62  378.0   560.0( 66%)   66    >   530 289.84    51    107
    2   204    884  2075    71    376.58     12.62     1.70      .43    2.13    8.7   167.2( 19%)    6         56   49.77    77    204
    3   307   1358  2150P  108*   240.37     36.76     2.90    27.44   30.34   80.4   400.0( 29%)   17         23  115.41    81    307

DOWN   :      3086   MAX = 151*   954.55    147.65    21.87    99.22  121.09  141.3  1127.2( 37%)                 455.01 PI =   92.2

    1   110    540  2250P  103*   230.04     17.19     3.60     7.17   10.77   71.8   511.9( 35%)   25         56   61.37    42    110
    2   206    558  2215    98*    98.77     12.82     5.48     4.64   10.12   65.3   510.9( 92%)   18         23   45.10    34    206
    3   309    854  2150P   70    256.20     11.12     3.43      .36    3.80   16.0   515.8( 60%)   21         39   45.03    81    309

UP     :      1952   MAX = 103*   585.01     41.13    12.51    12.18   24.68   45.5  1538.6( 79%)                 151.50 PI =   22.8


                                             <ROUTE TOTALS>


   TOTAL      TOTAL    TOTAL     TOTAL     TOTAL    AVERAGE     TOTAL      TOTAL
  DISTANCE    TRAVEL   UNIFORM   RANDOM    DELAY    DELAY     UNIFORM      FUEL   OPERATING PERFORMANCE  SPEED
  TRAVELED    TIME     DELAY     DELAY                         STOPS      CONSUM     COST      INDEX
 (VEH-KM/H) (VEH-H/H) (VEH-H/H) (VEH-H/H) (VEH-H/H) (SEC/VEH)  (VEH/H-%)   (LI/H)                         (KM/H)


  1539.56    188.78    34.38    111.39    145.77    104.17   2665.8( 53%)  606.51    779.62    114.90      8.16 <TOTALS>

NOTE: PERFORMANCE INDEX IS DEFINED AS:

     PI = DELAY + STOPS

NO. OF SIMULATIONS =  17  NO. OF LINKS = 266  ELAPSED TIME =  2392.9 SEC.
```

```
1 PRINCE SHAKER STREET                                                         CYCLE:  125 SECONDS,   60 STEPS   PAGE 15

 LINE    CARD                                                   TERMINATION CARD
  NO.    TYPE

  560     90      0      0      0      0      0      0      0      0      0      0      0      0      0      0      0

 --- PROGRAM NOTE --- END OF JOB!
1
```