Optimization of Traffic Signal Systems

THOMAS C. PITMAN
Signal Design and Construction Engineer
Indiana State Highway Commission

INTRODUCTION

Many individuals in traffic engineering have become aware of the very few tools readily available for putting theory into practice. The reason is that most of the signs, symbols, pavement markings, regulations, and traffic control devices are placed in operation at the mercy of the driving public and thus many fine theories lose all practical value due to the narrow acceptance of the driving public. This is not a discouraging fact because this inability to incorporate the many brilliant innovations is due to human limitations of motorists and our own exacting standards, we wish to achieve, before we accept a theory as a practical solution. This is not peculiar to our profession alone, but is common to many business and society functions. The point to be made is that theory can be applied to a traffic signal system to produce results which are quite acceptable to our professional standards and also to the driving public.

The best theoretical system must run the gauntlet of the motorists—the acid test. Reflecting upon the dismal nature of the items which influence the flow of traffic: left turn movements, parking movements, loading and unloading, slow, fast, and inattentive drivers, etc., one must remember that these various items, causing failure of traffic signal systems, occur upon an intersection-to-intersection basis. The system works throughout the whole segment and as stops occur due to improper driving habits at a particular intersection, it is possible to overcome this failure at the very next intersection and the thwarted motorist has a reasonable chance to pass through the rest of the system as designed. In other words, the traffic signal system develops a pattern for all the signals along a given segment of roadway. This pattern occurs again and again in exactly the same manner throughout the whole system and also individually from signal to signal. Failure of the entire system to move traffic usually represents a failure of the roadway capacity to service demand volumes.
A well designed and effective traffic signal system has very little if any effect upon the capacity of the traveled way, however, it will greatly increase the efficiency and economy in moving traffic.

TIME-SPACE DIAGRAM FOR A TWO-WAY TRAFFIC SIGNAL PROGRESSION

The actual performance on paper of establishing a traffic signal system is one which is cloaked in mystery. I have inspected, and have been taught several methods and procedures all of which are very complicated, unreasonable, and laborious. Many are familiar with some of these rather inappropriate methods, and because of the time involved have not attempted to employ them.

Below is a method for preparing a time-space diagram for a two-way traffic signal progression. The physical tools include: paper, pencil, a triangle and scale. The basic theory was provided in a paper entitled *A Method for Synchronizing Traffic Lights* by Morgan and Little. The graphical portion of the solution is my own attempt to provide a quick and reliable result which can be readily transformed into data for field use. The theory will be referred to as the Morgan-Little method. Briefly, it states that any two-way progressive traffic signal system, with equal band widths in each direction, is some form of an alternate system. It means all signals in the system form two groups, a zero-offset group and a 50 percent offset group.

**Graphical Solution (0 and 50 Percent Offset Group)**

The first step is to plot on the horizontal axis the various intersections along the segment of roadway making up the system. On the vertical scale, time in percent is plotted. Experience provides the approximate running speed for the system in question. Using this speed, in feet per second, the time in seconds to travel from one end of the system to the other is computed. This is then converted into percent using the cycle length. The travel time in percent is rounded off to the nearest 50 percent. By definition, there are only two offsets. Therefore zero or 50 percent of the elapsed time from the first signal to the last signal must be some multiple of 50 percent. Compute this in seconds and reverse the original computation and determine the new design speed.

Consider the example in Fig. 1. Note that the signal system is 2840 feet long; it is downtown in La Porte, Indiana, with parking on both sides of the street. It would be very difficult in this situation to expect to obtain an even 25 mph average running speed through such an
Fig. 1. This figure shows a chart for a graphical solution of a two-way progressive traffic signal system with equal band widths in each direction—LaPorte, Indiana.
area. It has been my experience, that in similar situations, 20 mph speeds are appropriate for such a location. Using 20 mph, and converting it to feet per second, a design speed of 29.5 feet per second is obtained. Dividing 2840 feet by 29.5 feet per second, the total elapsed time for moving through the system, is 96.3 seconds. Since a 60-second cycle was previously determined to be the most appropriate cycle length, 96.3 seconds is 160 percent for a 60-second cycle. This percentage is rounded to the nearest 50 percent which in this case is 150 percent; 150 percent on a 60-second cycle is 90 seconds. For the system this represents a speed of 31.6 feet per second or 21 mph. In some cases it may be necessary to alter the cycle length five to ten seconds in order to produce a design speed which is appropriate.

The reason for establishing the over-all elapsed time to the nearest 50 percent is to locate the offset of the first and the last signal in the system. Refer to Fig. 2 and note the 50 percent band widths are plotted for each direction showing an elapsed time of 150 percent from the first signal to the last signal in both directions. Intermediate signals are now examined to obtain proper phasing. The Morgan-Little theory states that all two-way traffic signal progressive systems are some form of an alternate system. In other words, if all traffic signals have equal splits, each signal has a possibility of only two offsets, zero or 50. Another way of referring to this is called offset phasing. All the signals in the system fall into two groups. Those signals which turn green at the same time and those which turn green 50 percent after the first group. With this in mind, now locate the individual signals green time at the proper location with an offset of either zero or 50 percent, by assuming all signals possess a 50-50 split. On the time space diagram the beginning of green is placed either at zero or 50 percent whichever allocates the most green within the theoretical 50 percent band widths, both bands are examined, as shown in Fig. 2 (solid lines). It is then possible to establish the actual band widths for such a theoretical system as shown by Fig. 2 (broken lines). In any time-space diagram preparation, the steps taken previous to this are exactly the same.

**Signals Without 50-50 Split**

Now refer to those signals which in reality do not have a 50-50 split and place the actual split about the center line of the previously located 50 percent green time—Fig. 3. After the existing splits have been placed upon the time-space diagram in the prescribed manner, the actual band widths of a system can be plotted as in Fig. 3. Note that if an increment of green time is added or subtracted to or from the
Fig. 2. Graphical solution assuming all signals have a 50-50 split—LaPorte, Indiana.
theoretical 50-50 green split, the offset changes from our originally established one which evolved from an assumed 50-50 split. The amount of this change may be stated as the increase or decrease in the original
offset amounts to one-half of the increment of increase or decrease in
the green period from the assumed 50 percent value. For example: An
increase to 60 percent green time from an assumed 50 percent, the
offset decreases 5 percent. Decreasing the 50 percent green to 40 per­
cent, the offset must be increased 5 percent. This is true because of
the use of the Morgan-Little theory which actually states that the mid­
point of a green will coincide with the mid-point of green for another
signal or be exactly one-half cycle out of phase. There should always
be two groups or phases (the only other possibility being a simultane­
ous system), therefore there are two such center lines (horizontal in
this case). The same statement of course may be applied to the red
periods.

Offsets Adjusted to Actual Splits

Now consider the theoretical group of offsets which have been ad­
justed to the actual splits, and form them into data which may be
installed in the control box. One may add or subtract any equal incre­
ment to this group as desired. Try to achieve a minimum number of
offset settings which fall within the red period of their respective signal
cycles. After this has been accomplished, these values are ready for
installation on the controller dial. The master controller offset is de­
termined as if it were one of the local controllers.

This process may seem complicated to one not familiar with it but
after using it just two or three times, the steps become very logical
and it is easily followed. With this paper as a guide, one will be able
to analyze and prepare a time-space diagram for any system within
a couple of hours.

FACTORS AFFECTING A PROGRESSIVE SYSTEM

Leading and Lagging Left Turn Arrows

In a progressive system do not be concerned with the respective
merits of leading or lagging left turn arrows, but establish them from
a progressive standpoint. In other words, referring to Fig. 3, and look­
ing at the intersection of Michigan Street, to install a left turn arrow
for eastbound traffic, it should, without question, be leading at this
intersection, and conversely, to have a left turn arrow for westbound
traffic, it should be of the lagging variety. If this is done, there is no
alteration of the respective band widths. At the intersections where the
band widths cross in the center of the green, as at the next intersec­
tion to the right, Monroe Street, it is more difficult to install any type
of left turn arrow and not alter the already established band widths,
however, in this particular case, depending upon one's preference for leading or lagging arrows, it might be possible to increase the split for the major street forming additional time for the left turn arrow and thus avoid disturbing either band.

Two or More Master Controllers

Frequently rather complex systems are found, which over years of development, have approached or inter-twined with one another. The problem is two or more master controllers hooked to their respective signal systems, but not to each other. In this case a handset system is formed between the masters. To establish a progressive system between them, they of course, must operate on exactly the same cycle length. An offset is established between two adjacent signals, one belonging to one master controller and one belonging to another master controller for progressive movement. By going into the field and measuring the actual offset in existence between these two signals, one can compute the time one master must be held up, or stopped, until the desired offset relationship between the two adjacent signals results. After this has been accomplished it is easy to check this relationship from time to time to make sure power failures or other malfunctions have not distorted the desired condition.

The Handset System

It is possible to run the multiple master system on two or more cycle lengths and still keep the systems in progression by allowing the desired dials to continue in operation even though they are not being used for signal operation at all times. For instance, for dial two to work during the morning and evening rush hours, and dial one to work during all other times, synchronize the two masters on both dials respectively (requires two coordination operations as described above) and do not stop either dial in the master controller when the other is actually called for in operating the signals. Dial transfer takes place exactly as in any other system at the local controllers without exception but the master dials never stop. The above is possible because all traffic signal dial motors of the common varieties are synchronous electric motors and run very much like your kitchen clock. It is possible to establish entirely “handset systems” and they will work very efficiently with only minor visual inspection required to insure that they have not become disrupted.

By way of illustration—many are familiar with the two one-way streets which serve the eastside of Indianapolis—New York Street and Michigan Street. Outside of the mile-square area there is no cable con-
necting the individual controllers for a length of approximately three miles on each street, yet very good coordination is evolved with this handset method. The limiting feature of the handset system is that only one pattern can be obtained. Dial transfer and split change cannot be accomplished and still form a progressive system. Do not confuse this handset progressive system with the method given above for coordination between two masters.

Systems With Three Patterns

Many systems employ three patterns, morning peak, evening peak and off peak utilizing all three dials with only one reset being used on each dial out of the available three on each dial. Many times we do not change the split but we wish to change the progressive pattern and do not realize, or at least do not take advantage of, the possibility of not having to dial transfer in order to change the traffic signal systems pattern. In my opinion, we should not dial transfer unless it becomes absolutely necessary and the only absolute reason for this is a required change in split and this normally occurs at only a few intersections throughout a given system. When we call for dial transfer three or four times during a 24-hour period, our system must be maintained in top-notch condition in order for this to occur without malfunction. This operation requires not only good electrical circuitry maintenance but also all of the mechanical aspects of the controller must work superbly. During the winter months for instance, the morning peak dial lies idle from mid-morning until early the following morning. In extremely cold weather, lack of excellent maintenance quickly shows because this dial will not operate properly and if dial transfer is not accomplished at one intersection during any peak period, when usually we are trying to favor one direction over another, the system is in trouble.

Three Patterns With One Dial

Most of the signal companies provide three distinct offset settings on each dial. In order to change the pattern of progression all that is required is to change the reset value. With this in mind, it is possible to operate the system on one cycle length and one split with three different patterns using only one dial, the standard of course being one pattern for morning peak, another for evening peak, and one for off peak. The three patterns are called for by changing the reset and the only mechanical unit involved is closing one relay for the whole system and of course this is mainly electrical in operation. This reduces drastically the mechanical difficulty which is encountered when a
whole system must dial transfer at each and every signal controller. It is quite possible to incorporate such a method of changing patterns without dial transferring on most of the systems. However, it may be absolutely necessary to change the split at various locations throughout a given system. When this is required and the reset method on one dial is being used, a simple jumper between the required reset pole and the dial two or dial three pole on the back panel, will accomplish dial transfer at this location only and the proper reset will coordinate this dial; thus the possibility for mechanical failure is associated with very few of the signals in the system.

COMPUTER PROGRAMS FOR DETERMINING OFFSET RELATIONSHIP

Many are aware of the various programs in existence for use on computers for determining the offset relationship between a given group of traffic signals to form them into a progressive system. The program which we have used most extensively in the central office traffic division, is one that was prepared by the Massachusetts Institute of Technology which utilizes the Morgan-Little theory.

Computer Input and Output Data

The computer calculates very rapidly and therefore the computer program is more detailed than the graphical solution presented here. In the graphical solution, in establishing offsets, the first and last signal were formed into perfect coordination which established the theoretical band widths and the offsets of the intervening signals were located to match these bands. The computer takes each individual signal and associates all the other signals either in phase or out of phase with the signal in question using a given speed it determines the maximum band width for this situation. It serves this maximum band width and proceeds to the next signal phasing all other signals in the system either in phase or out of phase to establish maximum band width at the given speed for this situation. After it has done this for each signal within the system, it compares the various band widths which have been established for the given speed and chooses the maximum one and gives the information in its output format. In cases where two or three signals used as a base, produce the maximum band there is an intricate tie breaking procedure which the computer follows to find which of these arrangements produces the most efficient operation and this winning situation is reproduced in the output format.

Since cycle length and speed may be varied in this program, the writer normally introduces two or three cycle lengths unless the cycle
length has already been established by other factors and always several speeds within a desired range in increments of about \(2\frac{1}{2}\) miles per hour and the output format gives the information showing the band widths resulting from the various speeds and cycle lengths thus allowing a decision which considers maximum band width, appropriate speed and cycle length. It takes more time to get the input data together, which includes block to block distances, the split of each signal, the volume in vehicles per hour in both directions and of course the speed and cycle length, then it does for the computer to give the solution.

**Computer and Graphical Solutions Compared**

With repeated use of the computer and the graphical solution, detailed here, I do not find any great advantage of the computer over the graphical method except for the ability to examine many situations in about the same length of time that it would take to solve one graphically.

With this information, which the computer produces and files for every system analyzed, it is possible to come up rapidly with new plans for changing future conditions.

**Recent Computer Programs**

There are new computer programs which have come out recently that are a bit more complicated than the one illustrated above which we use extensively. The newer programs require additional information. After selecting speed, both a maximum and a minimum as well as cycle length at a maximum and a minimum value, the computer produces an optimum situation for both speed and cycle lengths within the range which has been set up. One of the programs, also as a method of a standard operation, produces the equal band width situation for both directions and gives the speed for each cycle length for all standard cycles from 45 seconds to 120 seconds. These programs at this time have not been utilized by our division to the extent that we can actually place a value upon their service for our needs, but the first program that I illustrated is very sound and requires only basic information and produces multiple solutions in less than ten minutes.

In the future, if our needs increase and our systems become more complicated, I am quite sure that the other more complex programs will prove their worth to our industry.

**CONCLUSION**

Even with the computer at our fingertips it is still necessary for a traffic engineer to have at his command the graphical solution. First of all, most of the systems usually contain two, or not more than
four or five signals, and with a firm knowledge and understanding of the two-way progression (equal band widths in each direction), a time-space diagram can be evolved in just a matter of minutes. A system can be analyzed graphically in short order and it certainly would be a waste of time to reproduce this in a computer for a check since the computer goes through approximately the same procedure and provides the same answer. It is hoped that the graphical solution will prove that the preparation of a time-space diagram need not be overly complicated. It is also hoped that others will use it in every instance where there are two or more signals which need to be synchronized whether interconnection cable is available or not.
## ADDENDUM

**TRAFFIC SIGNAL SYNCHRONIZATION PROGRAM**

**IN-PUT DATA TSSP**

For 1620 Computer

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<th>Location: Laporte</th>
<th>Rd. &amp; St. Name: SR 2 (Lincolnway)</th>
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### CARD Data

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<tr>
<td>2</td>
<td>East Bound 600.0 Veh/Hr. West Bound 600.0 Veh/Hr.</td>
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### Data Table

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<th>Red Time Sec.</th>
<th>Intersecting Street</th>
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12 10