Sept. 15, 1970 J. S. WAPNER 3,529,286

CAPACITY DEMAND TRAFFIC CONTROL SYSTEM

Filed April 23, 1968 4 Sheets-Sheet 1

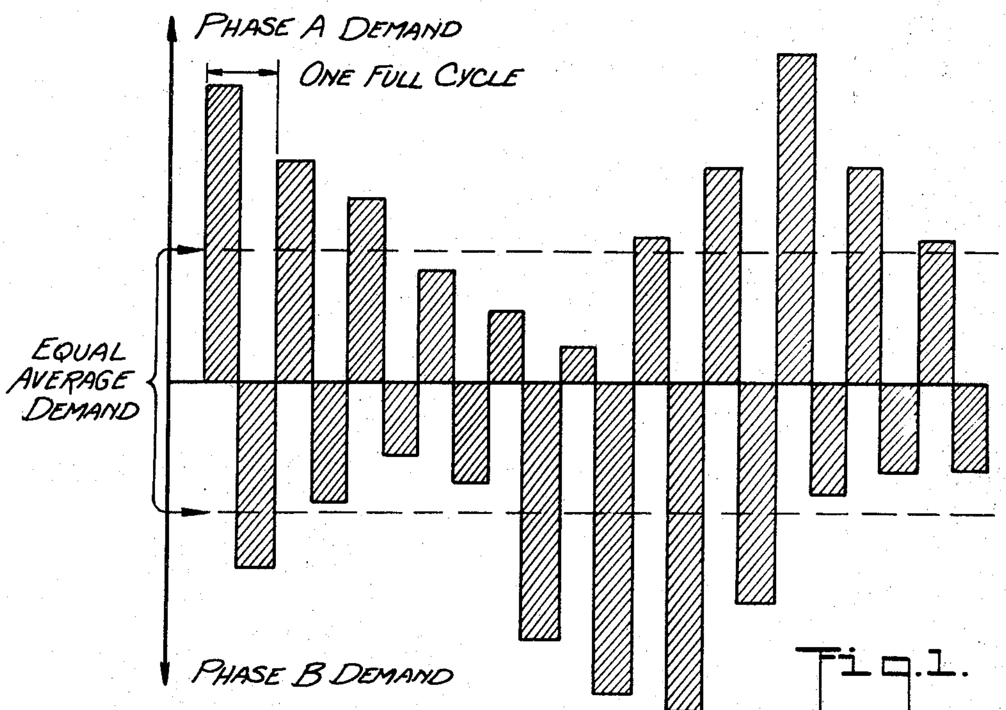


Fig.1.

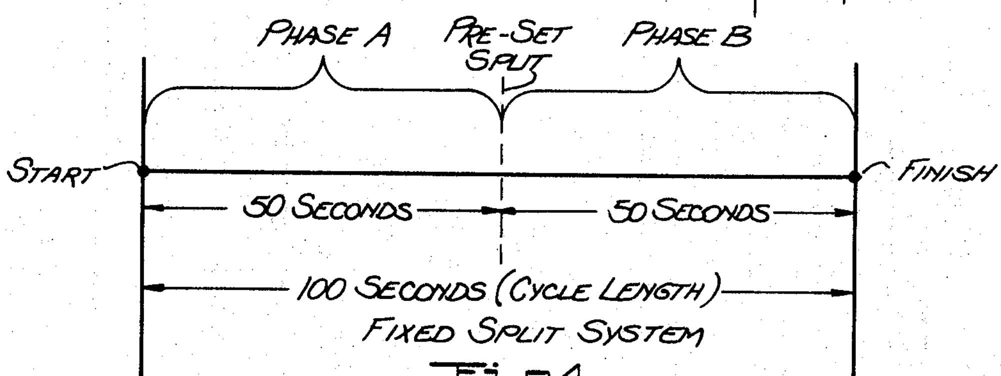


Fig.4.

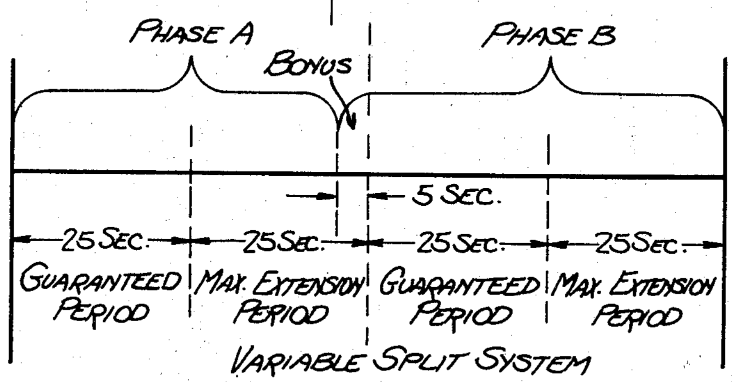


Fig.5.

INVENTOR.
JOSEPH S. WAPNER
BY Michael [signature]
ATTORNEY

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CAPACITY DEMAND TRAFFIC CONTROL SYSTEM

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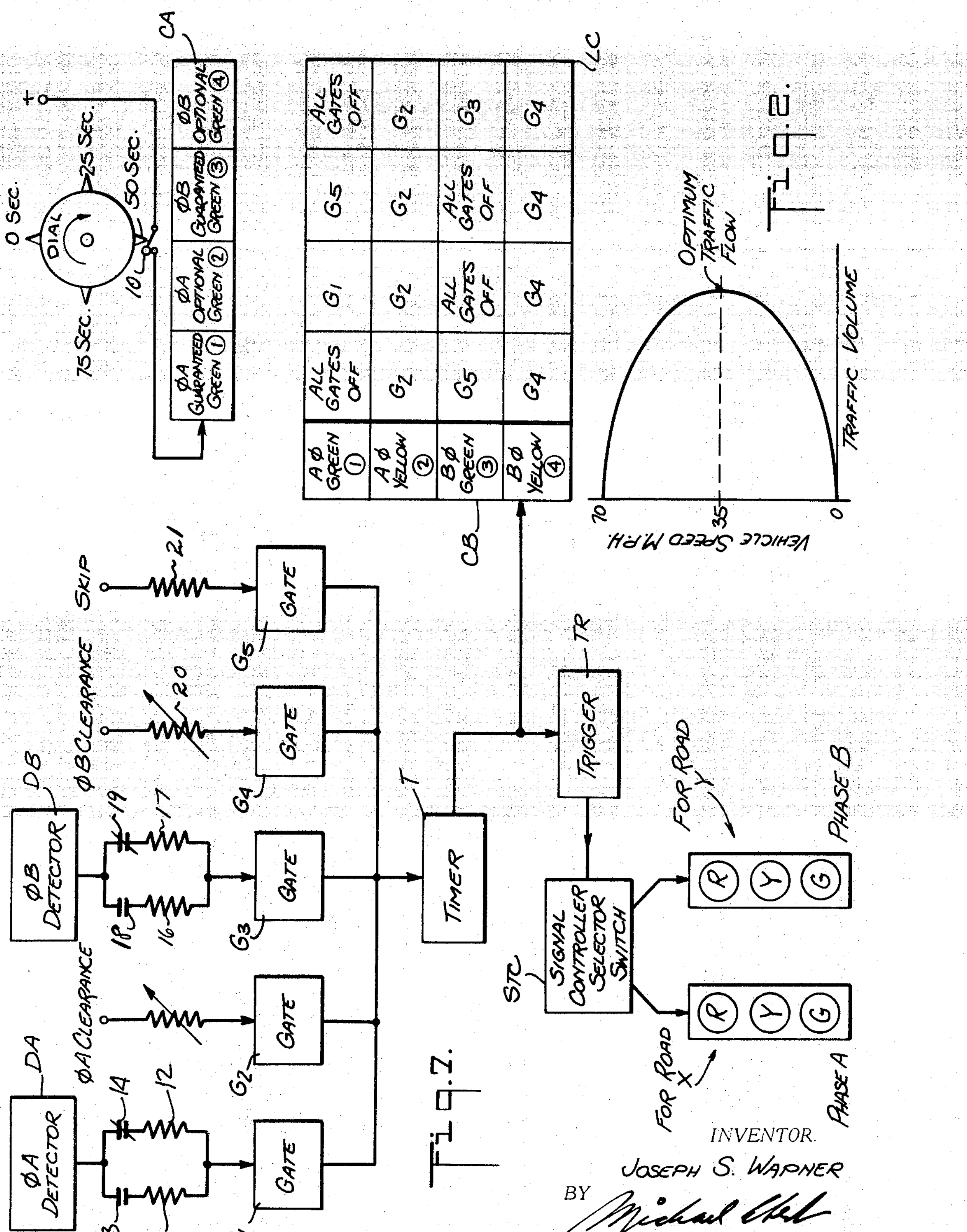


INVENTOR.

JOSEPH S. WAPNER

BY Michael Ebel

ATTORNEY

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Fig. 3.

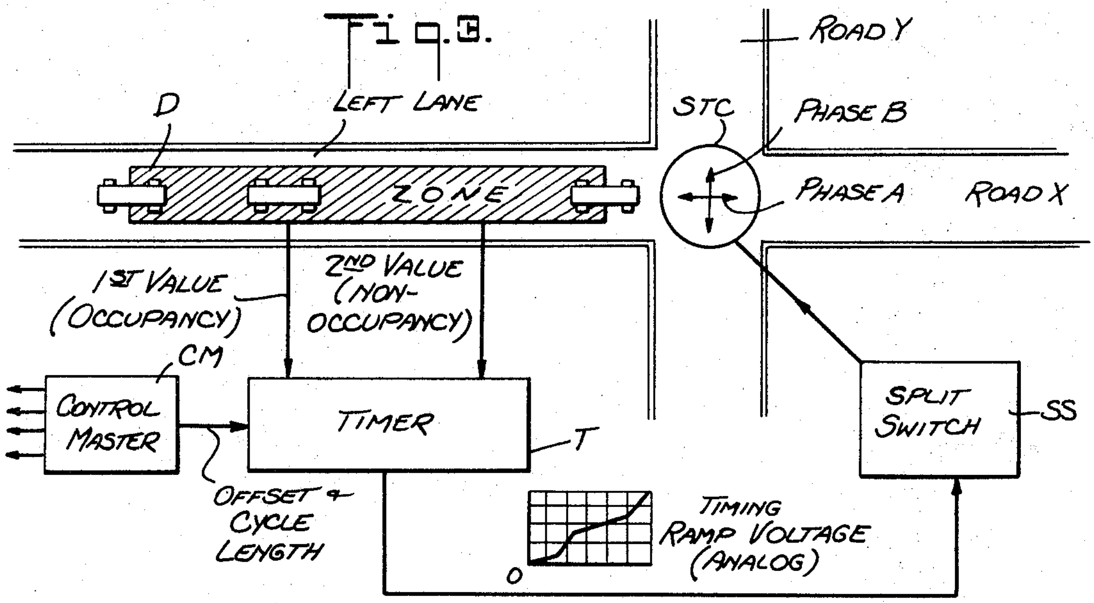
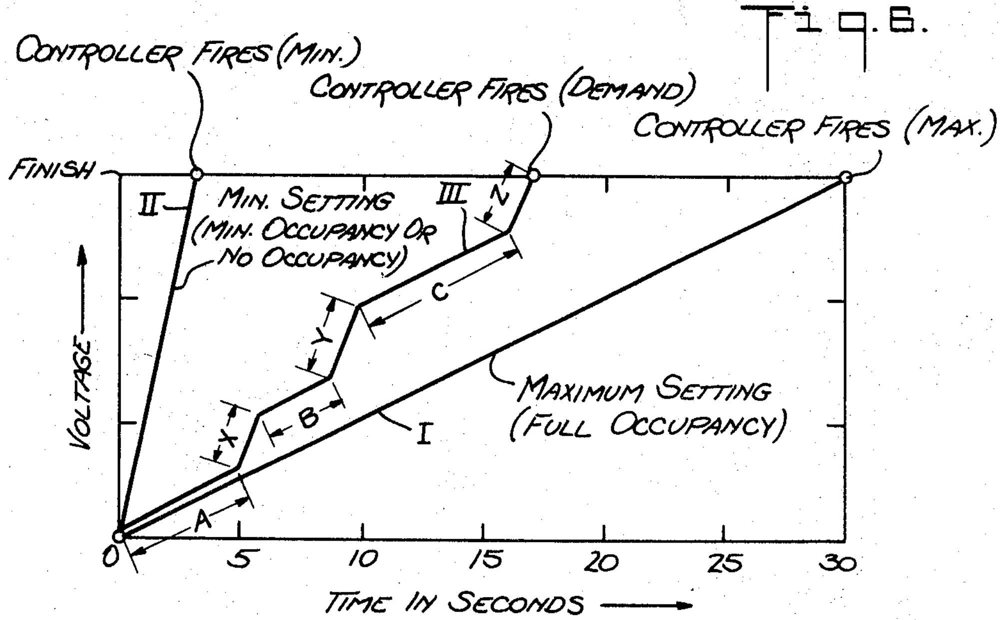



Fig. 6.




A = OCCUPANCY BETWEEN 0 AND 5 SECONDS

B = ADDITIONAL OCCUPANCY BETWEEN 6 AND 9 SECS.

C = ADDITIONAL OCCUPANCY BETWEEN 10 AND 16 SECS.

X = NO OCCUPANCY

Y = NO OCCUPANCY

Z = NO OCCUPANCY

INVENTOR.

JOSEPH S. WAPNER

BY Michael [signature]

ATTORNEY

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Fig. 8.

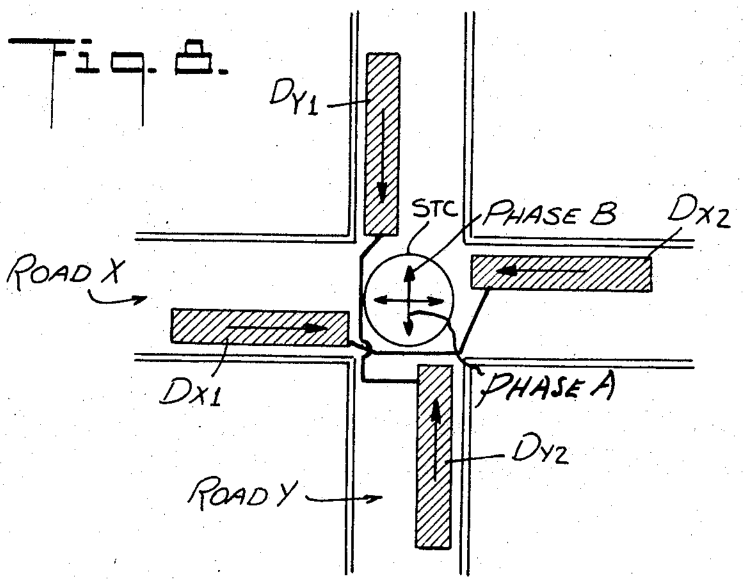
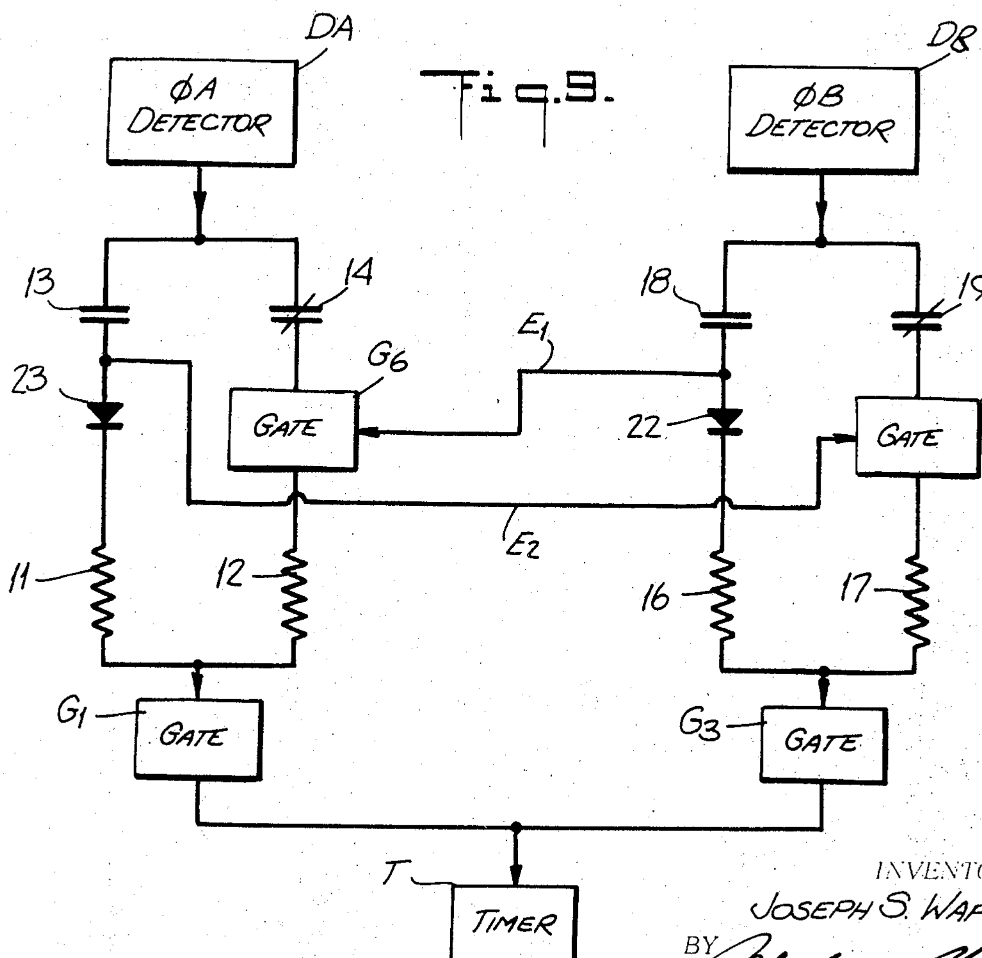



Fig. 9.




INVENTOR.
JOSEPH S. WAPNER
BY [signature]
ATTORNEY

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3,529,286

# CAPACITY DEMAND TRAFFIC CONTROL SYSTEM

Joseph S. Wapner, Levittown, Pa., assignor to Fischer & Porter Co., Warminster, Pa., a corporation of Pennsylvania

Continuation-in-part of application Ser. No. 637,783, May 11, 1967. This application Apr. 23, 1968, Ser. No. 723,495

Int. Cl. G08g *1/07*

U.S. Cl. 340—37 9 Claims

## ABSTRACT OF THE DISCLOSURE

A traffic control system in which local controllers are stationed at various intersections, the operation of these controllers being coordinated by a control master. Each local controller includes means producing a time cycle of traffic indications which sequentially in one phase accords the right-of-way along one traffic direction, and then in another phase, which is initiated at a preset split point, accords the right-of-way along the cross traffic direction. The time cycles of the controllers are initiated by the control master, which also determines the cycle length and the offset therebetween. At critical intersections, apparatus is provided to divide each phase into a guaranteed period and a variable extension period. The duration of the extension period is determined by the actual capacity demand during the phase according the right-of-way, which capacity demand is the time required by prevailing traffic to clear the intersection under efficient flow conditions. A split is effected at the conclusion of the extension period, and the difference in time between this point and the preset split point is added as a bonus interval to the subsequent phase.

This application is a continuation-in-part of my copending application Ser. No. 637,783, filed May 11, 1967.

This application relates generally to traffic control systems, and more particularly to a traffic controller located at an intersection and responsive to changes in capacity demand.

In modern traffic control systems of the type disclosed, for example, in Pats. 3,241,104, 3,241,107 and 3,241,110, traffic controllers are dispersed along arteries or within a traffic grid and are coordinated by a control master. In such systems, each local traffic controller is situated at an intersection which may, for instance, be formed by the main artery and a cross street. Included in this traffic controller are means producing a local time cycle of traffic signal indications which sequentially in one phase accords the right-of-way (green) along the artery, and then in another phase, accords the right-of-way along the cross street before returning the right-of-way to the artery.

Considering a full local time cycle as 100%, the transfer of the right-of-way is set to occur at a predetermined percentage point within this cycle. This set point is generally referred to as the "split." Thus the split determines the relative phases of the local time cycle in which the right-of-way is given to the respective intersecting directions.

The time required for the local controller to complete a full cycle is designated the cycle length which, in practice, may be in the order of forthy to one hundred and twenty seconds. If, therefore, the cycle length is selected to one hundred seconds, and the split occurs at 70%, the right-of-way in the above example will be given to artery traffic for seventy seconds, and to cross-street traffic for thirty seconds.



In order to coordinate the operation of the various local controllers, the control master acts to establish individual displacements of the local time cycles from a master cycle which serves as a reference. This displacement is commonly referred to as "offset." In a situation in which all of the local controllers operate simultaneouly, that is, where all controllers switch to green at the same time, the controllers then have a "zero offset."

When applied to a traffic grid, measurements of traffic in one traffic direction may be used to vary the offset of the local controllers to afford a progression of right-of-way in that direction, and measurements of traffic in another direction further vary the offset of a group of traffic controllers along one street with respect to a further variation of offset of a group of traffic controllers along streets parallel to the one street, thereby affording a progression of right-of-way in said other direction while maintaining the progression in said one traffic direction. Thus a traffic grid requires complex offset changes to promote the uninterrupted flow of traffic in various directions.

In a fixed-time traffic control system, the generally prevailing traffic pattern is not measured but is predicted on a historical basis. No attempt is made to correct for momentary deviations from the predicted pattern. But in a traffic measuring system, information regarding volume, prevailing direction of flow and cross-traffic data, is accumulated and used periodically to update the settings of the local controllers.

The maximum rate at which changes can be made is limited by practical considerations of the effect on traffic flow resulting from a change of either offset or cycle length. Unless these changes are introduced in a gradual manner, stoppages and traffic shockwaves will be experienced. This basic limitation in the rapidity at which control intelligence at the master can be acted on by the local intersection controllers, is a major obstacle to efficient operation. Even though traffic is essentially a random phenomenon, in order to cope with traffic variations, a philosophy of "averages" has been developed to create control patterns which at least approach actual traffic conditions.

Heretofore, three basic offset conditions have been employed in traffic control systems. These three conditions are based on the relative difference or a predetermined differential beteween the value or count of traffic which is characteristic of volume, for example. These conditions are usually referred to as "average offset," "inbound offset," and "outbound offset." "Average offset" prevails when both traffic flows are substantially equal, or unequal but within a predetermined difference of value. "Inbound offset" prevails when the inbound traffic exceeds outbound flow by a predetermined amount, while "outbound offset" prevails when the reverse condition exists. These offset conditions may be further broken down into finer degrees of offset conditions.

In order to supervise the various local traffic controllers to take into account previaling traffic conditions, the conventional master selects one out of a half-dozen or so patterns of operation which determine the preferred offset for progression, as well as the cycle length and the split, thereby to establish the mode of operation of the local controllers at the various traffic intersections within the system.

Despite the complexity of such systems, they nevertheless fail to operate efficiently, for the system is not sensitive to random, cycle-by-cycle fluctuations in traffic conditions which take place at individual intersections, and particularly those that occur at critical intersections.

If the traffic pattern at a given intersection in the course of a day were more or less predictable, it might be possible to program the operation of the local signal controllers to minimize delay at all times, so that the controllers would function in one manner to take care of peak traffic in the course of the day, and would function in other ways when other predictable patterns are encountered. However, while traffic peaks may generally be anticipated at given intersections, the actual pattern of traffic is variable in the course of any day that a programmed controller falls far short of attaining the desired objective.

It is for this reason that computers have been developed to measure prevailing traffic parameters and to actuate the local signal controller as a function of actual rather than estimated parameters. In traffic engineering, the three main parameters which are usually measured for this purpose are speed, density and volume. Traffic density is a measurement of the number of vehicles occupying a unit length of roadway at a given moment. Traffic speed is the speed of vehicles flowing upon the roadway, while traffic volume is the number of vehicles passing a given point during a specified time period.

In computers of the type heretofore devised for automatic actuation of a signal controller, the computer is designed to measure one or more of the parameters of density, speed and volume, by means of digital techniques. In density measurement, the number of vehicles entering a given space is recorded, and the number departing from the same space is recorded, in order to arrive at a count representing the number within the space. In volume measurement, the number of vehicles passing a given point per hour is counted. In speed measurement, the time it takes for a vehicle to travel between two spaced points is determined.

The nature of vehicles is such that they do not lend themselves to treatment as digits. Hence computers for traffic control whose operation is digital are incapable of effecting optimum control under fluctuating traffic conditions. If all vehicles were of the same size and if they travelled at the same speed, they could readily be handled as digits for purposes of computation. But this is not actually the case and by counting the number of vehicles passing a given point, the count attained during a prescribed interval does not reveal the true nature of traffic. For instance, twenty trailer trucks successively passing a point during a given interval will give a low volume count, whereas during the same interval many more small cars could have passed, yet the trailer trucks create a much heavier traffic condition.

Thus the minor improvement in efficiency gained by the use of sophisticated computers does not justify the complexities and expenses involved in supplanting the conventional programmed master controller, for whether a computer or a master controller is used, neither one approaches optimum efficiency in that they are both insensitive to random traffic variations on a cycle-to-cycle basis at critical intersections in the system.

Accordingly, it is the main object of the present invention to provide in a traffic control system, means to determine "capacity demand" at an intersection, that is, the time required for traffic to clear an intersection under efficient flow conditions, the capacity demand measurement being used to vary the split on a cyclic basis.

More specifically, it is an object of the invention to provide a local traffic controller at a critical intersection in a traffic control system, which local controller has a time cycle which is split into two phases, each of which has a fixed guaranteed period and a variable extension period, the latter period being determined by the capacity demand during the phase having the right-of-way.

A significant feature of the invention is that as long as traffic is moving under conditions which fully utilize the road capacity, the green light is extended up to the maximum time allotted. If, during the extension period of a given phase, the capacity demand falls below the maximum utilization level, the signal is changed and the



unused portion of the extension period is transferred as "bonus time" to the other phase. This, in effect, results in a system that is coordinated for the progressive movement of traffic, while having a variable split to take advantage of random cycle traffic variations.

Briefly stated, these objects are attained in a traffic control system wherein local traffic controllers are situated at various traffic intersections, each controller being provided with a timer that operates a signal indicator to produce a local timing cycle of traffic signal indications which sequentially in one phase accords the right-of-way along one road and then, in another phase, accords the right-of-way along the cross road at the associated intersection.

The local controllers are coordinated by a control master which initiates the operation of the timers and regulates the length of the time cycle at the local controllers as well as the offset therebetween. At key intersections in the system, apparatus is provided which acts in conjunction with the local controller to vary the split in the local time cycle from a predetermined set point as a function of capacity demand without however changing the cycle length.

This apparatus is constituted by a detector disposed along the road within a zone extending from the intersection to a point removed therefrom by a distance sufficient to include a plurality of successively arriving vehicles, which distance is substantially equal to the headway between successive vehicles at optimum speed. The detector acts to sense the presence of any vehicle or a portion thereof within the zone or the absence of all vehicles therefrom. Circuit means are coupled to the detector to produce a first value representing a state of zone occupancy and a second value representing a state of zone non-occupancy.

The timer, whose operation is initiated by the control master to cause the signal indicator to accord in one phase a right-of-way to traffic flowing along the road, proceeds to time out for a guaranteed period to accord this right-of-way regardless of traffic conditions, which fixed period is followed by a variable extension interval whose duration is determined by the time it takes to go from a start to a finish point at a relatively slow rate determined by said first value and at a faster rate determined by said second value, whereby the duration of the extension interval is an analog of traffic actually flowing through the zone.

A split occurs upon the conclusion of the extension interval, whereby the second phase, which also has a guaranteed interval, is afforded a bonus or supplementary period whose duration is the difference between the termination point of the extension interval and the predetermined set point. Thus the local controller is dynamically sensitive to random variations in traffic conditions, and yet retains its fundamental timing cycle so that its operation may be coordinated by the control master with other local controllers in the system whether or not they include means to vary the split.

For a better understanding of the invention, as well as other objects and further features thereof, reference is made to the following detailed description to be read in conjunction with the accompanying drawings, wherein:

FIG. 1 is a graph illustrating cyclic variations at a traffic intersection;

FIG. 2 is a curve showing traffic volume versus speed;

FIG. 3 is a schematic diagram of a local controller at an intersection operating in conjunction with apparatus in accordance with the invention;

FIG. 4 shows a conventional timing cycle;

FIG. 5 shows a timing cycle which is modified to vary the split;

FIG. 6 is a graph illustrating the operation of the timer in the local controller;

FIG. 7 is a block diagram of a local traffic controller in accordance with the invention which includes a logic circuit to operate the signal selector switch;

FIG. 8 schematically illustrates an actual detector arrangement at an intersection; and

FIG. 9 is a modified form of local traffic controller.

## THE BASIC PROBLEM

In the design of a typical traffic control system, the following premises are generally accepted:

(A) Regardless of how traffic flow information is obtained or computed, one cannot on this basis change offset and cylce length in each cycle without introducing undesirable traffic effects. All possible hope for a synchronized, progressive movement of traffic would be lost if a cyclic change of offset and cycle length were made. In practice, traffic can respond to fifteen cycle changes without serious upset, five cycles being used to gradually make the change and ten cycles to evaluate the effect thereof.

(B) Most arterials include at least one or more intersections which may be characterized as "bottlenecks" in the sense that their "green" time demand approaches that of the arterial road. These key intersections are major limiting factors to the traffic volume which the arterial can handle.

(C) One does not change the "split" in the local timing cycle as a function of traffic conditions at a particular intersection on a cyclic basis even at key intersections. Changes in split can be made only when changes are made in offset and cycle length and on a predictive basis as a function of "averages" or in response to computed traffic values.

It will now be shown that premise C above, which has been generally accepted in the design of traffic control systems, is the main reason why such systems have heretofore failed to optimize traffic, and that unless the split is modulated on a cycle-to-cycle basis in response to actual traffic condition, the system will fail to operate efficiently.

Referring now to FIG. 1, a cyclic traffic demand diagram of a "bottleneck" intersection is shown. Demand in phase A during each cycle is shown above the zero line, and that in phase B is shown below the zero line. Demand is given as a function of time rather than volume. The criterion is the time required to clear traffic, for volume does not take into account the variable introduced by the ratio of slow-moving vehicles, road capacity, turning movements, and other factors. The use of volume introduces a factor predicated on "averages" requiring a "best guess" approach.

The diagram illustrates a situation where the "average green time" demand for both roads is equal. Typically, there are random variations on a cyclic basis. It will be evident there are cycles on each road where the "average" time is either too much or not enough for the demand. Clearly during the periods of "wasted green time," the traffic on the other road could have been moving and a pile-up of traffic prevented, while pile-up in the long run reduces flow efficiency.

It will also be seen that regardless of how accurate the predicted "average" is, it cannot prevent this loss of efficiency due to unnecessary stoppages. The combined "averages" can be reasonably used as a setting for total cycle length as long as means are provided to vary the split on a cyclic demand basis, otherwise the total length has to be increased to compensate for the "wasted green time."

This is a self-defeating action because it gives rise to a further waste of "green time." The prior practice of refining data-gathering and computing functions to afford a highly accurate prediction of "averages" yields a poor ratio of increased efficiency per dollar spent. Increased efficiency can only be obtained by attacking certain fundamental problems. It is these problems which shall now be analyzed.

The two major obstacles to efficient traffic flow are unnecessary stoppages and "wasted green time." Each stoppage results in a loss of flow efficiency as a function of start-up time. Given a few slow-starting vehicles such as trucks and buses, this reduction in efficiency will be drastic. Wasted green time results in a direct reduction of the volume of traffic which an intersection can handle. These factors must be optimized in order to have a control system that will move traffic efficiently. To attain this objective, some of the theories heretofore unchallenged in the traffic control field, must be reexamined. One theory is that of control based on volume. Let us see how valid this concept is. For example, what is the total time needed for a hundred vehicles to clear an intersection? Would it be the same for all of the following condition?

(a) A hundred passenger vehicles with no turning movements;
(b) Variable mixe of both slow and fast vehicles;
(c) Turning movements introduced;
(d) Vehicles stopped at the signal and having to start again.

The answer to this question would have to be prefaced with, assuming an "average" mix of vehicles, making an "average" number of turning movements, and being stopped an "average" number of times, it will take so many minutes to clear the intersection. Inasmuch as there can be a few hundred percent difference in the time of transit, depending on the nature of these variables, a computation to the tenth decimal place of the average does very little to increase efficiency.

What information is therefore essential in order for a control system to optimize flow? The only logical answer is capacity demand. This obviously is a variable only loosely tied to volume. All factors, such as the number and type of vehicles, turning movements, etc., make up the composite that constitutes capacity demand. A truck and a passenger car each have a basic difference in capacity demand, further differences depending on whether these vehicles are stopped moving, or turning. The salient factor is that this capacity demand be dircetly related to the "green time" requirements of the intersection.

The next logical question is how can this information be obtained? Referring now to FIG. 2, there is plotted the relationship of speed to volume. The maximum flow occurs at about thirty-five miles per hour. This speed is a variable within limits depending on the geometry of the road, frequency of crossroads, etc. But for a given road it is a repeatable constant. It therefore is a reasonable assumption that, for a given road, a queue of vehicles all traveling at this speed will result in the optimum flow.

Assuming that the optimum speed is thirty-five miles per hour, an unexpected phenomenon is encountered, namely the headway between vehicles becomes a constant. This is due to two factors motivating the driver. One is his desire to keep up with the car in front, and the other, to braking distance required in case of sudden stop by the vehicles ahead of him. Without conscious effort on the part of the driver, the headway becomes a repeatable exponential as a function of speed.

This exponential effect is related to the braking distance required for different speeds and is an inferential measurement of optimum flow. If the headway is less than that required by the optimum speed, the result is a lower volume flow due to overload capacity. If the headway is greater, this too gives rise to reduced volume flow and it is an indication that the capacity is under-utilized.

Thus, headway is an inferential measurement of traffic flow under dynamic conditions. However, the capacity demand of "green time" requirement at the intersection deals with slow-starting vehicles, turning movements, and so on. It is at this point that capacity demand must be measured.

## THE INVENTION

To explain how capacity demand is measured according to the invention, we now refer to FIG. 3, which shows a detector D in the left lane of a main road X which intersects with a crossroad Y. Placed at the intersection of these roads is a traffic signal controller STC which shall, for reasons of simplicity, be of the type having only red and green signals.

Controller STC is capable of functioning in a phase A giving a right-of-way only to traffic in main road X, and in a reverse phase B in which this right-of-way is given only to traffic in crossroad Y. The combination of these phases constitutes the operating cycle of the controller, the transfer point therein being designated as the "split." The transfer from one phase to another is effected by a split-switch SS, which in turn is actuated by a timer T, whose operation is supervised by a control master CM. Timer T is also subject to the control of the detector D in a manner to be later described.

Detector D is a loop which encompasses an elongated zone in the left lane in road X, the length of the zone being sufficient to include a plurality of successively arriving vehicles, the front edge of the zone being adjacent the intersection. As long as any vehicle or a portion thereof lies within the zone boundaries, the circuit associated with detector D will produce a first value which represents a state of occupancy, but when no vehicle or any portion thereof lies within the zone boundaries, a second value is established representing a state of non-occupancy.

If, therefore, a platoon of vehicles is traveling through the detector zone and one or more vehicles thereof lies fully or partially within its boundaries, detector D yields the first value, but when the headway between two vehicles in the traveling platoon is such that at a particular time no one vehicle falls within the zone boundaries, the detector yields the second value. While a loop detector has been disclosed for this purpose, it will be obvious that other known forms of presence detectors may be used within the scope of the invention.

The effective length of the loop detector is made equal to the headway at the optimum speed. Thus if the optimum speed for traffic flow is thirty-five miles per hour, the length of the loop is made 75 feet. The result is that irrespective of cause, the detector produces the first value as long as vehicles are spaced by distances less than the headway at optimum speed. This is an indication of full capacity demand. As soon as the vehicles start spacing out at distances greater than the headway at optimum speed, this indicates a lower than capacity demand and a decreasing need of "green time," the detector then producing the second value. In accordance with the invention, the ratios are set so that as flow efficiency starts decreasing, the green-time allocation is rapidly diminished. This takes into account all the variables which make up "capacity demand."

Once information analogous to "green time demand" is available, it can be used to operate an arterial control system on a demand basis rather than a predicted "average" mode. At an intersection of two roads X and Y, having approximately equal average green-time demand, the split is normally preset for two equal intervals of green time. Thus, as shown in FIG. 4, assuming a cycle length of one hundred seconds under the control of the master controller MC, the cycle is divided into two phases A and B having intervals of fifty seconds each. If, now, instead of two intervals, the timing cycle is divided into four intervals, whereby each phase has an extension period based on demand, for both X and Y, a system of control based on actual demand is realized. In practice, this system, as shown in FIG. 5, operates in the following manner.

The fifty-precent time (fifty seconds) allotted to each road is divided into two intervals. The first period is preset and guaranteed, the second or extension period is on a variable basis predicted on actual demand. As an example, let us assume again, a cycle length of one hundred seconds, and that the guaranteed period is equal to twenty-five percent of the cycle length (25 seconds), while the extension period has a maximum duration of twenty-five percent, at the conclusion of which the preset split occurs.

When road X obtains the light in phase A at the start of its twenty-five percent period, it retains the green light on a guaranteed basis. At the end of this period it goes into the second or extension period. All or part of this second period is retained, depending on the green-time demand requirements as sensed by the loop detector in road X, which measures the efficiency of flow. As long as traffic flow utilizes the full road capacity, "green" is retained up the maximum of the twenty-five percent extension period. The green is then returned to crossroad Y.

However, if the full 25% extension period is not required, the signal wil change sooner at, say, twenty seconds. he difference between the conclusion of the extension period and the preset split point is a "bonus time" for Y, and in this instance, the bonus time is five seconds, which supplements the twenty-five second guarantee period of phase B.

The operation of green time for the Y road is similar. In a case where the X demand is light and the Y demand is heavy, X would get only its twenty-five percent guaranteed time during phase A, while in phase B, Y would get X's twenty-five percent extension period at bonus time, as well as Y's guaranteed period and its extension period. This would result in a split of twenty-five percent of the cycle for X and seventy-five percent for Y.

If the reverse condition were true, X would get the seventy-five percent, and Y would get the twenty-five percent of the cycle. Obviously the split can be varied within these or any other percentages as a function of actual demand in a cyclic mode. This arrangement also protects the progression because there is a guaranteed period always starting at the same time for the local controller, and it is possible, therefore, for the control master coordinate the operation of this controller with the other controllers in the progression.

The use of a variable split dependent on actual demand reduces the requirements for sophisticated central equipment. The function of master control MC is now only a means to determine the prevailing direction of traffic and cycle length. These are simple computations calling for a limited number of decisions. Three cycle lengths and three offsets would be more than adequate. If loop detectors were used, in a similar manner as described for intersection demand, to supply information to the control master to determine cycle length and offset, it would have greater validity than existing means for this purpose.

Volume measurements at the intersection for the determination of cycle length and offset have the obvious drawbacks, in that such data, by itself, does not include the other variables which are necessary to arrive at actual demand. To appreciate the distinctions between volume measurement and capacity demand, let us exmine two possible situations.

Situation (a)

A volume detector is installed in the arterial where vehicles may be counted as they pass by. From the averaging and computation of this information, cycle length and offset has to be determined. On a count basis, a car and a truck are essentially the same. But the difference in demand is drastic if the truck is stopped and has to start moving. The cycle length computation must take into consideration these variations. Otherwise, we must make assumptions of what the mix will be.

Situation (b)

Let us take a loop detector whose geometry is such as to be capable of measuring efficiency by capacity demand, as previously described. Install this loop at a minor intersection where it is feasible to use a fixed split. If the capacity demand is measured as a proportion of the "green" time available, it would provide valid information to determine actual requirements for cycle length and offset. The fact that this information is taken at a point where traffic is stopped and must restart, will provide data of the sort necessary to optimize the cycle length. The cycle length required consists of the time necessary to clear vehicles which have been stopped at an intersection. If there are a significant number of slow-starting vehicles in the traffic mix, the capacity demand is entirely different when these vehicles have to restort as compared to when they are moving. The placement of the loop to measure the start-up capacity demand is the only feasible way of obtaining "green" time or true cycle-length information.

With this description of the basic elements that constitute an arterial control system, we can now demonstrate how these elements can be used to optimize traffic flow.

The typical arterial problem is to move traffic along a highway that is intersected by a large number of minor roads and a few major roads that act as the basic limitation to flow. While in theory the aim might be to get the greatest flow through every intersection including the minor ones, in practice this might not be true for efficient control.

Thus, if the minor side roads were entirely closed, the tendency would be for traffic to jam up at the critical intersections. In many cases, the minor street signals are used to "store and release" traffic at a pace that the critical intersections are able to handle. Therefore, the critical problem is to promote passage of traffic through the "bottlenecks." A fixed split of, say, sixty-five percent and thirty-five percent, on the minor intersections, would pass any traffic that the critical intersections can handle without introducing any undue delays.

The real key to this system, of course, is the use of a variable split intersection controller which is responsive to capacity demand on a cyclic basis at the critical intersections. With the emplacement of loop detectors to measure the actual "green time" demand and having a controller that is responsive to these variations, it becomes possible to obtain maximum efficiency. In this type of operation it is feasible to interlace the platoon effect of traffic flow with the minimum number of stoppages and lost green time.

Thus the requirements of the control master MC have been minimized. Its function of providing synchronizing pulses, "offset" and cycle length, has been retained. The components necessary to arrive at the right selection of offset and cycle lengths have been reduced and simplified through the use of capacity-demand measuring loops. There can be no inversion of control due to measuring volume flow in a traffic condition that has reduced it to a trickle. Volume would give an indication for decreasing cycle length, whereas capacity demand would call for increased demand under these circumstances. In fact, this approach has so simplified the requirements of the central equipment, that use of digital computers is unnecessary.

Timer T is operatively coupled to control master CM which acts to initiate the time cycle as well as to control the length thereof and the offset. The split has a predetermined set point. Detector D is coupled to a circuit which yields a first value when the zone is occupied, and a second value when the zone is unoccupied, to produce an extension timing interval whose duration depends on these values. The timer is arranged so that when its operation is initiated, it provides a guaranteed period which has a fixed duration to accord a right-of-way during the signal phase in effect regardless of traffic conditions. At the conclusion of the guaranteed period, the timer is then under the control of the detector, which produces the extension interval.

The duration of the extension interval is determined by an electronic circuit generating a voltage which rises along a ramp from a zero or minimum level at the start point to a predetermined voltage magnitude or maximum level at the finish point. The circuit details are disclosed in my above-identified co-pending application. As shown by the various curves in FIG. 6, the amount of time, in seconds, it takes this voltage to rise from the start to the finish point represents the variable extension interval which constitutes an analog value reflecting capacity demand. While the extension-period timer is described as electronic in character, it will be obvious that equivalent results are obtainable by a mechanical or motor-driven arrangement.

The electronic circuit is arranged so that when it is responsive to the first value it runs slowly, this being represented by the maximum setting voltage curve I, where it will be seen that it takes thirty full seconds for the voltage to rise from start to finish. When, however, the timer responds to the second value, it runs much faster. This is represented by the minimum setting curve II, where it will be seen that the voltage runs from start to finish in exactly three seconds, which is ten times as fast as the response to the first value. Since the invention involves a preset guaranteed period, in practice, the minimum period is made nearly zero time.

If, therefore, there is no traffic in the zone at the commencement of the extension interval and this condition continues, the circuit will time out quickly, as in curve II, to cause a split after the set minimum interval. But if the traffic is such that the zone remains occupied by one or more cars, the circuit will time out slowly, as in maximum setting curve I, to cause a split only after a thirty-second interval, thus affording the maximum time to clear traffic through the intersection before the split occurs.

If, on the other hand, the traffic pattern is fluctuating so that the zone is intermittently occupied, the detector will yield first and second values in a sequence reflecting this condition. Consequently, as shown in curve III, the voltage will rise quickly when a second value is in force, then slow down when a first value takes effect, so that the timing interval between start and finish will be made up of successive slow and fast increments (A, X, B, Y, C and Z).

The total extension interval (curve III—seventeen seconds) will therefore be an analog of actual traffic conditions, and will reflect the physical length of the vehicles as well as speed, starting time, headway, and other parameters which come into play and to which the detector is sensitive, thereby reflecting the actual capacity demand.

In order further to explain why the timer interval constitutes an analog of traffic conditions, some examples will now be given. Assume that a single car is passing through the detected zone at twenty miles an hour. As long as this car or a portion thereof lies within the zone boundaries, a first value will be produced which reflects the state of occupancy. As soon as this car is fully outside of the zone boundary, the second value is established. In a simple, practical form, these values may be created by a relay which is caused to occupy one switch position when the detector field intercepts the presence of a vehicle, and another switch position when no vehicle is present. In one switch position a timing circuit having a long time constant is introduced into the electronic circuit, while in the other switch position a timing circuit with a short time constant is introduced therein.

If now a second car travels through the zone at exactly the same speed, but the second car is longer than the first, though it will take exactly the same time for the second car to go from the beginning to the end of the zone, it will necessarily take longer for the second car body to clear the end of the zone. This will be reflected in the relative periods of the first and second values produced by the travel of the second car. Hence while a digital system will not be able to distinguish between the first and second cars in the example given, in that each car gives a single count and each produces the same speed indication, the analog system will afford an appropriate distinction, for the resultant extension interval will reflect the longer occupancy period of the second car and therefore have a greater duration.

Let us now by way of another example assume a platoon of cars traveling through the zone, all cars having the same speed and being spaced apart with a headway of, say, one hundred feet. The resultant first and second values will, of course, reflect this headway in the relative periods in which the two values are established. If now another platoon of cars travels through the zone and the cars in this platoon are identical to those in the first platoon and are moving at the same speed, but with a headway of two hundred feet, this distinction will show up in the values established by the detector and by the resultant timing-in period. Thus, regardless of how traffic fluctuates, the analog system will produce an analog voltage which is a proper reflection of the existing capacity demand, and the instant of phase split in the signal controller will be such as to produce right-of-way signals promoting optimum flow efficiency.

Thus if the detector loop is immediately vacated, the extension period will time out on its minimum setting; if the loop is continuously occupied, the extension period will time out on its maximum setting; and if the loop experiences a combination of occupancy and non-occupancy states, it will time out at some intermediate point between the minimum and maximum time setting.

It is to be understood that the guaranteed period may be provided also by an electronic circuit but one having a fixed time constant to provide a guaranteed interval of predetermined duration. The maximum setting I of the electronic circuit producing the extension period is the preset point at which the split normally is to occur, hence when the extension period is terminated at its minimum setting II or at its intermediate setting III, the difference between this setting and the maximum setting I is transferred as bonus time to the next phase and is added to the guaranteed time thereof.

FIG. 3, for reasons of simplicity, shows a detector D on only one side of the main road X with respect to the intersection of roads X and Y. However, since traffic on road X arrives from either direction toward the intersection, in practice a second detector linked to detector D is installed on the other side of the intersection. Thus, as shown in FIG. 8, in an actual installation, on the left side of road X, there is placed a detector $D_{x1}$, while on the right side thereof, there is placed a detector $D_{x2}$, the two detector loops being connected in series to the associated timer so that traffic is sensed on road X regardless of whether it approaches the intersection from the left or right.

A pair of similiarly intercoupled detectors $D_{y1}$ and $D_{y2}$ is installed on either side of the intersection on road Y to provide an extension interval in phase B and to grant bonus time to phase A should traffic conditions warrant. Thus, in an actual installation, there will be two pairs of detectors placed at the intersection operating in conjunction with the timing system.

The loop detectors at the local controllers may be used to supply intelligence as to capacity demand at the associated intersections as a basis for computing the split, offset and cycle length at the control master. Such information from the loops affords a more realistic basis for efficient "average setting" for arterial control.

## THE ELECTRONIC SYSTEM

Referring now to FIG. 7, I shall now show how the invention may be applied to a critical traffic intersection at which there is already installed a conventional local signal controller STC operating in conjunction with the usual signal selector switch. The controller operates a set of lights red-yellow-green (R–Y–G) for phase A in road X, and another set of lights (R–Y–G) in the reverse phase B for traffic in the cross-road Y.

In a conventional traffic controller, in addition to the signal controller, there is also a so-called "dial" unit D which is a slotted drum driven by a synchronous motor, the drum being so constructed that pins can be inserted in the drum to provide spaced pulses on a cyclical basis.

These pulses are produced by a microswitch **10** connected in series with a direct voltage source, the microswitch being sequentially actuated by the pins on the rotating drum. These pulses are ordinarily used to advance the signal selector switch in signal light controller STC to activitate the appropriate signal lights. Usually the signal selector switch is a solenoid-operated stepping switch having the appropriate number of heavy duty contacts for the signals and the appropriate number of steps determined by the phase requirements.

The conventional dial unit D also has the capability of having more than one pattern of split—usually three. Up to three dial units may be used to provide a choice of cycle lengths, split and offset. A control master is used to select these variables and synchronize the system. To maintain the proper relationship of the dial unit and the signal selector switch, automatic synchronization means are used for this purpose, such means being well-known.

As pointed out in the preceding sections of this specification, the difficulty in making conventional controllers responsive to traffic demand is due to the fixer nature of the selected pattern on dial unit D. This difficulty is overcome by the invention which at a critical intersection varies the split as a function of traffic demand. Since the selection of offset, cycle length and split as a function of "average" demand is already incorporated in a conventional controller, although the ability to respond to actual local traffic demand on a cyclic basis is not, it will now be shown how a conventional installation may be readily converted to operate in accordance with the invention. In practice, all of the auxiliary components to convert the system may be housed in a single compact container, so that such conversion may be quickly and inexpensively effected.

Let us first consider the operation of a conventional two-phase intersection controller with a 100 second background cycle having a 50% split. In this arrangement the desired pattern is realized by an appropriate setting of the pins in the dial unit in which the timing intervals within the cycle are as follows:

| Time in 100 sec. cycle | Phase A | Phase B |
|---|---|---|
| 0–48 seconds | Green | Red. |
| 48–50 seconds | Yellow | Red. |
| 50–98 seconds | Red | Green. |
| 98–0 seconds | Red | Yellow. |

In the above pattern, it will be evident that the ratio of green to red time available in phases A and B is fixed, regardless of actual traffic demand.

In the present invention, wherein the split is made of variable as a function of traffic demand, there is installed a traffic detector DA in road X to sense traffic demand in that road for phase A control, and a similar traffic detector DB in road Y for phase B control.

Detector DA acts through a gate $G_1$, which when operative, governs timer T, in the manner described more fully in connection with FIG. 3, to produce in the state of zone occupance a slow timing rate and in the state of zone nonoccupancy a fast timing rate.

To accomplish this result, two resistors **11** and **12** are provided, selectively operating in conjunction with a charging capacitor (not shown) to provide a timing rate depending on the resistor value in effect. The resistor which is selected is determined by switches **13** and **14**, the first being normally open and the second being normally closed in the state of zone non-occupancy, this relationship being reversed when the zone is occupied. Hence, when the zone is un-occupied, normally-closed switch **14**, makes resistor **12** operative to provide a fast timing rate, and when the zone is occupied normally-open switch **13** closes to introduce resistor **11** to provide a slow timing rate.

Since phase A includes a clearance light (yellow or amber) the timing of this signal is effected by connecting a timing resistor **15** to timer T through a second gate $G_2$.

Detector DB acts through a third gate $G_3$ which when operative in phase B introduces either resistor **16** or **17** into the timing circuit, depending on whether the zone is occupied or un-occupied, as indicated by switches **18** and **19**, to provide a slow or fast timing rate in the manner previously described.

Since phase B includes a clearance light, the timing of this signal is effected by connecting a timing resistor **20** to timer T through a fourth gate $G_4$. For the purpose of forcing the system to split, a "skip" resistor **21** is connected to timer T through a fifth gate $G_5$.

In order to arrange dial unit D to produce guaranteed as well as variable extension or optional timing intervals, the pins thereof are set at 0–25 –50 –75 seconds. It is to be understood that these settings are merely by way of example.

Operating in conjunction with dial unit D is an electronic counter CA which responds to the dial pulses to step successively from a position **1** representing phase A, guaranteed green, to a position **2** representing phase A, optional green, to a position **3** representing phase B, guaranteed green, and finally to a position **4** representing phase B, optional green, after which the cycle is repeated.

Timer T activates the signal selector switch of controller STC through a TRIAC or electronic trigger TR to cause the traffic light to assume the appropriate color. A second counter CB is coupled to the trigger, this counter having a first position **1**, representing phase A, green, a second position **2**, representiing phase A, clearance, a third position **3** representing phase B, green, and a fourth position **4** representing phase B, clearance.

The counters CA and CB are operatively coupled to a logic circuit LC of any standard design which on the basis of those counter positions which are coincident, determines which, if any, of the gates $G_1$ to $G_5$ will be operative, so that for some coincident counter positions all gates are "off" while for others a particular gate is "on." Functionally the system operates in the following manner:

(1) At the start of a cycle with the dial unit at zero seconds, counter CA and counter CB are both at their respective positions **1**, and the signal selector STC is at its first position (phase A—green and phase B—red). In this condition, as shown in the logic table LC, all gates to the timer are "off."

(2) After 25 seconds, which is the guaranteed green time in phase A, the dial unit D sends a pulse to counter CA which advances it to position **2**. With counter CA at position **2** and counter CB still at position **1**, gate $G_1$ is turned "on" by the logic circuit. This serves to connect loop detector DA for phase A to timer T, the timing then being responsive to actual traffic demand. The traffic demand sensed by loop detector DA determines whether timer T will time out before or after the 50-second pulse from dial unit D to counter CA.

(3) Assuming light traffic conditions, timer T will then time out prior to the 50-second pulse to counter CA. This will provide a time out pulse that advances counter CB to position **2**, the time out pulse also triggering the signal selector switch STC, as a consequence of which the signal given is phase A yellow and phase B red, the second signal position.

(4) At this point, counter CA is at position **2** while counter CB is at position **2** in which condition the logic circuit puts gate $G_2$ "on." Gate $G_2$ permits a preset clearance time for phase A to control the timer. When this times out, the resultant pulse from the trigger advances counter CB to position **3** and the controller to its third position, namely phase A, red—phase B, green.

(5) In this third position all gates are "off." What this has accomplished is to give the unused portion of green time in phase A to phase B as a bonus. Counter CB and the selector switch remain in this position until counter CA is advanced to position **3** by the 50-second pulse from the dial unit D. They also remain in this position for the phase B guaranteed green time between the 50-second and 75-second pulse.

(6) Let us now take the case where traffic is heavy in phase A and the 50-second pulse to counter A arrives before timer T has timed out in position **1** of counter CB. Inasmuch as the interval of time between the 50-second pulse and the 75-second pulse is guaranteed phase B green time, the signals must be forced to change. The operation of the logic circuit is such that with counter CA in position **3** and counter CB in position **1**, gate $G_5$ is "on." This puts resistor **21** in the timing circuit to provide a fast "skip" time, causing the timer to immediately time out, thereby advancing counter CB to position **2** and the signal selector to yellow. In this position, the clearance interval is timed and both the signal selector and counter CB advances to position **3**. In this operation, phase B receives no bonus time in that the traffic demand was such that phase A needed the full time.

(7) Between the 75-second pulse to counter CA and the zero time pulse, phase B, green, operates in the same manner as phase A does between the 25-second pulse and the 50-second pulse, these intervals providing optional green time. If traffic is heavy, the full time is used, but if light, the unused portion is given to the other road as a bonus. If for example, traffic were light in phase A and heavy in phase B, phase A would only be given it guaranteed green time (25 seconds) and B would be given A's optional green time as a bonus, as well as its own guaranteed green and optional green time for a total of 75 seconds. A reverse situation would give phase A 75 seconds and phase B 25 seconds, including clearance time.

(8) The fact that both phases have a guaranteed green time occurring at a precisely timed interval permits the coordination of both roads in a progressively timed signal system. It also permits the interlacing of uneven traffic as a function of traffic demand on a cyclic basis, with a marked reduction of many unnecessary stoppages.

Now if the control master, which determines the offset for the various local controllers, acts to initiate the guaranteed period at a given instant for phase A at a critical local controller which is provided with a variable split in accordance with the invention, and in the preceding phase B during the optional or extension interval, a bonus period is granted to the succeeding phase A, what this will do is to initiate the phase A guaranteed period sooner than the given instant determined by the control master to an extent determined by the bonus. This does not upset the basic offset relationship of the various local controllers, but it does act to give the critical local controllers which have been granted a bonus more time to clear traffic, to take care of a prevailing demand.

Consequently, as distinguished from conventional systems, the invention is sensitive to cycle-by-clcle fluctuations at the critical intersection while still maintaining the basic offset pattern essential to progression.

It is to be understood that in place of a motor-driven dial unit providing a sequence of pulses at preset points, the such pulse may be generated electronically. Similarly the signal selector switch may be an electronic unit using for example silicon-controlled rectifiers in conjunction with a counter having the required number of phases, rather than an electromechanical stepping switch.

## MODIFIED ELECTRONIC SYSTEM

In the arrangement shown in FIG. 7, if during the variable extension interval in phase A no traffic is detected in road X, the system functions to switch over to phase B after a minimum extension period has expired. However, if at this time no traffic is detected in the cross-road Y (phase B), the switch over serves no useful purpose, and one might just as well run the extension period in phase A for its maximum duration to take care of any vehicles which might arrive at a time beyond the minimum extension period.

Similarily, if during the variable extension interval in phase B, no traffic is detected in road Y, and there is also no traffic in road X, one might just as well run the extension interval in phase B for its maximum period, rather than switch over to phase A after the minimum extension period.

To accomplish this result, the system illustrated in FIG. 7 is modified in the manner shown in FIG. 9 by interposing a gate $G_6$ between normally-closed switch **14** and fast-timing register **12** in the phase A circuit, and by interposing a gate $G_7$ between normally-closed switch **19** and fast-timing resistor **17** in the phase B circuit.

Gate $G_6$ in phase A is rendered operative by a voltage $E_1$ derived from the junction of switch **18** and an isolation diode **22** in the phase B circuit when switch **18** is closed, whereas gate $G_7$ in phase B in rendered operative by a voltage $E_2$ derived from the junction of switch **13** and an isolation diode **23** in the phase A circuit when switch **13** is closed.

In operation, switch **14** in phase A, which is normally closed and remains closed when no vehicle lies within the zone of the phase A detector, ordinarily places the fast-timing resistor **12** in the timing circuit. But if at this time there is no vehicle in the detection zone of phase B, then normally-open switch **18** remains open and no voltage $E_1$ is applied to operate gate $G_6$; hence, this gate prevents the completion of the circuit to fast timing resistor **12** and instead of the minimum extension interval, the circuit times out for its maximum duration.

Likewise, switch **19** in phase B, which is normally closed and remains closed when no vehicles lie within the detection zone of phase B, ordinarily places the fast-timing resistor **17** in the timing circuit. But if at this time no vehicle appears in the detection zone of phase A, then normally-open switch **13** remains open and no voltage $E_2$ is applied to operate gate $G_7$; hence, this gate prevents the completion of the circuit to fast-timing resistor **17** and instead of the minimum extension interval, the circuit times out for its maximum duration.

While there has been shown and described a preferred embodiment of capacity demand traffic control system in accordance with the invention, it will be appreciated that many changes and modifications may be made therein without, however, departing the essential spirit of the invention.

What I claim is:

**1.** In a traffic control system, a local traffic controller situated at a traffic intersection and provided with a timer which operates a signal indicator to produce a local time cycle of traffic signal indications which sequentially in one phase accords the right-of-way along one road, and then in another phase accords this right along the cross-road at the intersection; apparatus to vary the split in the local time cycle as a function of capacity demand, said apparatus comprising:

(A) a detector disposed along said one road within a zone extending from the intersection at one side thereof to a point removed therefrom, said zone having a length sufficient to include a plurality of vehicles arriving successively and being substantially equal to the headway between successive vehicles at optimum speed for traffic flow efficiency, said detector acting to sense the presence of any vehicle or a portion thereof within the zone or the absence of all vehicles therefrom,

(B) circuit means coupled to said detector to produce a first value representing a state of zone occupancy and reflecting the headway between successively-arriving vehicles at the zone when said headway is no greater than the length of the zone, and a second value representing a state of zone non-occupancy,

(C) means coupled to said circuit means to render the timer responsive to said first and second values after a pre-set guaranteed interval subsequent to the instant at which timing is initiated in the phase according a right-of-way along said one road, said first value effecting timing at a relatively slow rate and said second value effecting timing at a faster rate from a start point to a finish point to produce a variable extension interval which is an analog of traffic flowing through the zone and hence of capacity demand, and

(D) means operative at the conclusion of said interval to effect said split.

**2.** In a traffic control system wherein local traffic controllers are situated at traffic intersections, each controller being provided with a timer which operates a signal indicator to produce a local time cycle of traffic signal indications which sequentially in one phase accords the right-of-way along one road, and then in another phase accords the right-of-way along the cross-road at the associated intersection, the local controllers being coordinated by a control master which initiates the operation of the timers and regulates the length of the time cycle at the local controllers as well as the offset therebetween, at least one of said controllers acting in conjunction with apparatus to vary the split in the local time cycle as a function of capacity demand, said apparatus comprising:

(A) a detector disposed along said one road within a zone extending from the intersection at one side thereof to a point removed therefrom, said zone having a length sufficient to include a plurality of vehicles arriving successively and being substantially equal to the headway between successive vehicles at optimum speed for traffic flow efficiency, said detector acting to sense the presence of any vehicle or a portion thereof within the zone or the absence of all vehicles therefrom,

(B) circuit means coupled to said detector to produce a first value representing a state of zone occupancy and reflecting the headway between successively arriving vehicles at the zone when the headway is no greater than the length of the zone, and a second value representing a state of zone non-occupancy,

(C) means coupled to said circuit means to render the timer responsive to said first and second values after a pre-set guaranteed interval subsequent to the the instant at which timing is initiated in the phase according a right-of-way along said one road, said first value effecting timing at a relatively slow rate and said second value effecting timing at a faster rate from a start point to a finish point to produce a variable extension interval which is an analog of traffic flowing through the zone and hence of capacity demand, and

(D) means operative at the conclusion of said interval to effect said split.

**3.** In a traffic control system as set forth in claim **2**, wherein said last-named means includes a logic circuit.

**4.** In a system as set forth in claim **1**, wherein said detector includes an induction loop disposed in the road.

**5.** In a system as set forth in claim **2**, wherein said local time cycle has a predetermined length, the arrangement being such that if the variable extension interval falls short of the point at which a split is set to occur, the remaining period is given as a bonus to the succeeding phase.

**6.** In a system as set forth in claim **2**, further including a detector disposed along the other road at one side of the intersection, said detector operating in conjunction with circuit means producing said first and second values, which values are applied to said timer.

**7.** In a system, as set forth in claim **2**, further including a second detector connected in series with said detector and disposed along said one road within a zone extending from the intersection at the opposing side thereof.

8. In a system, as set forth in claim 6, further including a second detector connected in series with the detector disposed along the other road and disposed at the opposing side of the intersection.

9. In a system as set forth in claim 8, further including means coupled to the detectors disposed in said one road and in said other road to maintain said extension interval for a maximum period in the event there is no traffic in either road.



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