AN ANALYSIS OF COMPUTER APPLICATION TO TRAFFIC CONTROL SYSTEMS

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James Richard Taylor

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AN ANALYSIS OF COMPUTER APPLICATION

TO TRAFFIC CONTROL SYSTEMS

By

James Richard Taylor

AN ABSTRACT OF A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
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ABSTRACT

AN ANALYSIS OF COMPUTER APPLICATION
TO TRAFFIC CONTROL SYSTEMS

by James Richard Taylor

Traffic control systems are employed to provide a rapid and efficient flow of traffic and to reduce traffic delays and congestion. Traffic signal control systems currently employed in our urban areas lack the flexibility and responsiveness to perform these functions adequately. Computer controlled systems have the potential of providing the flexibility, responsiveness, accuracy and speed of reaction required to control and regulate urban traffic.

This study covered the description and analysis of three computer controlled systems and a comparison of the following selected factors: (1) the detection devices used to provide the systems input data; (2) the methods of processing the input data; (3) the control measures activated by the systems; (4) the time required to react to changing traffic conditions; and (5) the degree of human control required to operate the system.

The following are the methods used in the study: (1) a review of the literature relating to the subject of computer application to traffic control systems, and (2) personal interviews and correspondence with manufacturers

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of computer and detection equipment, traffic engineers of cities employing or planning to employ computer controlled systems and research centers and organizations involved in similar or related studies.

The literature was surveyed to determine what has been accomplished in this field and what trends were developing. Interviews and personal correspondence with interested agencies and individuals were to determine the types of systems currently in operation, the results obtained from limited pilot operations, and the modifications and improvements projected for future systems.

This descriptive study of computer controlled systems included an analysis of their purpose, operational principles, vehicle detection units employed, processing of input/output data, and the control measures activated to solve or reduce traffic problems. The efficiency of the systems in relieving traffic congestion by reducing vehicle delays and increasing road production were compared.

It was concluded that the employment of computer controlled traffic control systems would provide a more efficient and responsive control system. Substantial decreases in vehicle delay, increased road production and a resultant decrease in traffic congestion were the major benefits to be realized.

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INTRODUCTION

Major cities throughout the world are faced with the ever increasing problem of devising traffic control systems which will provide a rapid and efficient flow of traffic in and through metropolitan areas.

Initially, one thinks of a smooth, well coordinated and efficient traffic control system in terms of personal convenience and pleasure. Every automobile driver has at one time or another been caught in the throes of a traffic jam in which individual tempers and engine temperatures rise at an alarming rate. Irritated drivers who are late getting to work, or to the beach, or to other destinations imprecate other drivers, the police, the city, and anyone else who may be at fault for the traffic system or lack of a system. Thus irritated, a disregard for safe driving practices and attitudes develops and all too often the end result is an accident or series of accidents, which reflect their cost in property damage, crippling injuries and death.

In addition to these well known and well publicized costs, there is the high economic toll exacted by traffic delays and congestion. These costs are not readily apparent to the average motorist and taxpayer. The estimated annual cost of traffic congestion in New York City is $1,082,200,000.

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This cost includes excess taxi meter fares, excessive oil and gasoline costs, automotive repairs, more rapid depreciation of automobiles, increased insurance premiums due to more accidents, diversion of additional police personnel to traffic duties, and other costs created by the delay in services.[1] This cost, when estimated on a national scope, presents a vast waste of our economic resources. There is also a destructive effect on downtown businesses, property values, municipal tax structures, and on the economic health of communities in general. It has long been recognized that clogged traffic is not only a source of public inconvenience, but that it adds heavily to the cost of transportation and the price of goods and services to all consumers.

Traffic congestion problems have been building up for years. Urban streets represent a tenth of the nation's road system, yet must accommodate 50% of the total traffic. The result is that almost all major arterials in metropolitan areas have become chronic bottlenecks.[2]

The question that naturally comes to mind is what is being done about this situation? Traffic congestion has

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[1]Report of the Citizens Traffic Safety Board, Inc., New York City, New York, 1953, p. 3.

[2]John W. Gibbons and Albert Proctor, "Economic Costs of Traffic Congestion," Urban Traffic Congestion, Highway Research Board Bulletin 86 (Washington, D.C.: National Academy of Sciences-National Research Council, 1954), p. 1.

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reached intolerable proportions on most of our arterial routes. Construction of urban freeways will provide substantial relief to cities, but arterial routes must remain the urban transportation system's bulwark for providing traffic distribution services. At present, urban arterials are over-taxed in their ability to provide this traffic service.[3] To add to the problem, the number of automobile registrations grows at a much faster rate than our road improvement programs. The following illustrates the rapid and continuing growth of the number of registered motor vehicles in the United States.[4]

YEAR	TOTAL VEHICLES REGISTERED
1895	4
1900	8,000
1910	468,500
1920	9,239,161
1930	26,531,999
1940	32,035,424
1950	49,195,212
1960	73,795,182
1962	78,660,000

These totals, if they were to remain at their present level, would be problem enough, but it is estimated that by 1975 there will be 109,500,000 registered vehicles and by 1980 the figure will have increased to 120,000,000

[3]Jack Berman and Arthur A. Carter, Jr., "Increasing Traffic Carrying Capability of Urban Arterial Streets," Increasing Traffic Capacity of Arterial Streets, Highway Research Board Bulletin 271 (Washington, D.C.: National Academy of Sciences-National Research Council, 1960), p. 1.

[4]Automobile Facts and Figures (Washington, D.C.: Automobile Manufacturers Association, 1963), p. 18.

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vehicles.[5] It is obvious that the problem is not going to solve itself. Providing new and better highways is only a partial solution. Part of the solution must depend upon maximum utilization of existing and projected facilities. Major arterial streets must be used to their maximum capacity and efficiency. Utilization of these arterial streets depends to a degree upon the control measures exercised.

Traffic control measures currently in use can be divided into two primary or basic elements: human and mechanical types of control. In theory, a traffic officer could be employed at every potential trouble spot and possibly eliminate much of the congestion and delay. In practice, the number and quality of police personnel who can be assigned to traffic duties are limited. Mechanical control, although of great assistance, is limited in its control function. The primary limitation is that it is not responsive to immediate and changing conditions. Even the combination of human and mechanical controls, operating in a coordinated system, does not solve the problem. The basic limitations of each remain and, despite every effort, traffic congestion and traffic jams occur regularly.

The field of automation proffers a possible solution to this problem. It has the potential to employ automated systems controlled by electronic computers which will provide a control system less dependent on human control and

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[5] Ibid., p. 46.

more responsive to changing conditions. Speed, accuracy, responsiveness and flexibility would be the characteristics of such systems.

I. THE PROBLEM

Statement of the problem. The purpose of this thesis is to provide an analytical study of the use of computer controlled traffic control systems in relieving traffic congestion in urban traffic systems. This will include a descriptive study of proposed systems and a comparison of the following selected factors: (1) the detection devices employed to provide the system in-put data; (2) the methods of processing the in-put data; (3) the control measures activated by the systems; (4) the time required to react to changing conditions; and (5) the degree of human control required to operate the systems.

Limitations of the study. This descriptive study of computer controlled traffic systems and the comparison of selected, similar factors of each system will be directed at the capability of the systems to perform the proposed task of relieving traffic congestion by reducing vehicle delays. Certain limitations must be placed on the compari-son of these systems since they are either in the experi-mental or pilot operation stages and as such there has been little sustained field observation to test their actual capabilities. The frame of reference for the comparison must be based on a logical evaluation of the selected factors without regard to fixed standards of effectiveness. This is necessary since no operational standards have been devised or formulated against which the systems can be effectively compared. Each system operates on different principles of traffic flow and control and as such it is doubtful whether any attempt will be made to formulate a general standard for the automated systems. At this stage in the systems development there is insufficient test data to prescribe standards that would apply to a specific system. It is the consensus of traffic engineers involved in systems development that operating standards will not be formulated until additional test data are available and then the standards will vary according to the location of the system, weather and road conditions, and the type traffic involved.[6] With this limitation the comparison of selected factors employed in the systems will not provide sufficient data to draw conclusions as to which system is most effective, but only to make a logical deduction as to which system or combination of systems will probably be most effective.

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[6]Information obtained from personal correspondence with J. H. Auer, Jr., Principal Research Engineer, General Railway Signal Company, Rochester, N.Y., May 7, 1963; L. Casciato, Chief Engineer, Traffic Research Corporation, Limited, Toronto, Canada, March 3, 1963; Edward Gervais, Project Manager, Michigan State Highway Department, Lansing, Michigan, March 28, 1963; and Adolf D. May, Jr., Director, Expressway Surveillance Project, State of Illinois, Department of Public Works and Buildings, Chicago, Illinois, May 7, 1963.

__Importance of the study__. Providing an efficient and rapid traffic flow system in urban areas is a major police problem. The proposed use of computer controlled systems in selected critical areas or for city-wide use and in conjunction and coordination with other highway systems opens new horizons in the field of traffic control. An automated system would receive a continuous flow of information relative to traffic density, lane occupancy, and vehicle speed and time in the system. It would analyze the raw data and react by making almost instantaneous decisions to increase or decrease speed limits, actuate traffic control devices and reroute traffic as required. A system of this type would provide the police with a tool which would permit better utilization of police personnel and provide a more efficient and responsive control system. As an added benefit, it would provide a source of accurate and current traffic data to assist in future planning for civic improvements.

This study provides a source of information as to what is being done to solve the problem of relieving traffic congestion, what systems are available, what systems are proposed and what results can be anticipated from the use of these systems.

II. REVIEW OF THE LITERATURE

Reference material in the field of computer controlled traffic control systems is difficult to obtain. Since the field is relatively new, there are no published volumes or universally accepted systems which can be used as a research guide. Instead, as different cities and research organizations develop new systems or elements of systems, they publish articles in professional journals or present papers before interested organizations. The literature review for this study is concerned primarily with these articles and presentations. It is here that trends and advancements in the field of traffic control are found.

The Highway Research Board, an affiliate of the National Academy of Sciences-National Research Council, Washington, D.C., publishes in their periodic bulletins and board proceedings the results of the studies and experiments of traffic engineers and research organizations. In an extensive search of the literature dealing with current traffic control systems it is apparent that in most cases theories concerning vehicular traffic are inadequate or restrictive. The problem is approached from the viewpoint of past experiences and future predictions with little emphasis on what is occurring at the instant time. This approach results in systems characterized by a lack of responsiveness to immediate changes and fluctuations in the traffic picture. From this situation is created our traffic congestion, traffic jams and resulting slowdown or breakdown of the control system.[7]

According to Cass and Casciato, the trend has been toward the periodic appearance of specialized types of traffic signal equipment on the market which respond in one way or another to traffic movements. The growing tendency has been toward fairly heavy investments in the form of traffic signal modernization. While the equipment has added somewhat in improving traffic flow, its value is limited. It cannot detect congestion and often will systematically aggravate rather than improve critical traffic conditions. The solution lies in the direction of signal systems which respond quickly to variations in traffic flow and which do a great deal to reduce congestion and decrease vehicle delay.[8]

Gibbons noted that more recognition is gradually being given to the theory that intersections are the limiting factor in street capacity and the frequency of intersections is the chief cause of delay in urban traffic.[9]

Lewis, in his work on traffic platooning, found that

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[7]Philip A. Perchonok and Sheldon L. Levy, "Application of Digital Simulation Techniques to Freeway On-Ramp Traffic Operations," Highway Research Board Proceedings, Vol. 39 (Washington, D.C.: National Academy of Sciences-National Research Council Publications, 1960), p. 506.

[8]Sam Cass and L. Casciato, "Toronto Successfully Pioneers Automated Control of Traffic Signals by a General Purpose Electronic Computer," Traffic Engineering and Control, Vol. 4, No. 2 (London, England: Printerhall, Limited, June, 1962), p. 86.

[9]Gibbons and Proctor, op. cit., p. 7.

the timing of signals to produce a coordinated progressive system on an urban street has been the subject of considerable research but that there appears to be a dearth of literature on the subject of maintenance of vehicle platooning on urban streets and none on the extent to which vehicles remain together on an open road after leaving a signalized intersection. The study of platooning shows that a definite pattern of vehicle performance prevails and a traffic signal placed some distance down the highway from the issuing intersection would cause less delay to the traffic stream if coordinated in some way with the first signal than if allowed to operate in a random manner. The use of electronic computers to coordinate and actuate traffic control signals apparently has the capability to perform this important traffic function.[10]

Mathewson found that there is a trend to utilize electronic computers as simulators to provide the solution to such traffic problems as investigating the effects of traffic control devices in advance of installation and predicting the effects of proposed changes on the capacity of a facility. The concept of vehicle flow rate or, alternately, distribution of gaps finds general utility in approaches of both analysis and simulation. The physical

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[10] Brion J. Lewis, "Platoon Movement of Traffic from An Isolated Signalized Intersection," Vehicle Performance as Affected by Pavement Edge Lines and Traffic Signals, Highway Research Board Bulletin 178, 1958, p. 1.

model (simulator) encompasses both the structure (fixed facility) and the dynamics of the movement of intersecting streams of vehicles in terms of flow paths, queuing, proceeding ahead and turning subject to delays caused by cross-traffic and pedestrians.[11] Gerlough expressed the purpose of simulation on a computer as an experimental determination of phenomena which are too complex to study analytically and which may not be conveniently studied empirically in the real life situation.[12]

The body of this study will contain information obtained from, as yet, unpublished articles by D. L. Gerlough, F. A. Wagner, Jr., and the International Business Machines Corporation.[13] Each of these studies indicates that the implementation of computer controlled traffic control systems will relieve traffic congestion by reducing vehicle delays.

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[11] J. H. Mathewson, D. L. Trautman and D. L. Gerlough, "Study of Traffic Flow by Simulation," Highway Research Board Proceedings, Vol. 34, 1955, p. 522.

[12] D. L. Gerlough, "Simulation of Freeway Traffic by an Electronic Computer," Highway Research Board Proceedings, Vol. 35, 1956, p. 543.

[13] D. L. Gerlough, Notes on the Use of the Digital Computer for Traffic Signal Control (Canoga Park, California: Thompson-Ramo Wooldridge, Inc., n.d.); D. L. Gerlough and F. A. Wagner, Jr., Simulation of Traffic in a Large Network of Signalized Intersections (Paper to be presented at the Second International Symposium on Theory of Road Traffic Flow, Sponsored by the British Road Research Laboratory, London, England, June 25-27, 1963); International Business Machines Corporation, Computer Real Time Control of Traffic (A Presentation to the Commissioner of Traffic, Cleveland, Ohio, June 4, 1962).

III. STATEMENT OF METHODS USED

This is a descriptive study of computer controlled traffic control systems and a comparison of selected, similar factors of each system. The descriptive study of the systems includes a detailed analysis of their individual operation and functions. It includes the purpose, operating principles, detection devices, analysis of in-put data and the controls actuated to solve or reduce the problems presented. The frame of reference for the comparison of the selected factors will be a logical evaluation of their effectiveness as compared with each other.

The following methods are used in this study: (1) a review of the literature relating to the subject of computer application to traffic control systems, and (2) personal interviews and correspondence with the manufacturers of computer equipment, traffic engineers of cities employing or planning to employ computer controlled traffic control systems and research centers involved in similar or related studies.

The purpose of surveying the literature was to learn what has been done in the field of automated traffic control and to determine what trends, if any, were developing in this field.

The amount of information obtained from the review of the literature of itself was not sufficient in quantity or depth to reach any conclusions as to definitive actions being taken in the application of electronic computers to traffic control systems. For the most part, the published articles rarely described or discussed a complete or operational system, but rather dealt extensively with improvements or innovations to parts of systems. Similarly, manufacturers of computer equipment did not release or publish the results of their finished systems studies because of the competitive nature of the electronic computer industry and their reluctance to release this information until the system had been found acceptable and saleable. Therefore, great reliance was placed on the results of personal interviews and correspondence with recognized experts in this particular field.

Mr. J. H. Auer, Jr., Principal Research Engineer for General Railway Signal Company, Rochester, New York, was contacted since his firm deals extensively with the development of traffic detection equipment. They installed the equipment used on the John Lodge Expressway, Detroit, Michigan, and the Congress Street Expressway, Chicago, Illinois. Each of these installation projects were in fact field testing laboratories for evaluating surveillance and detection equipment. Valuable information was made available on detection equipment and also on a new parameter to the traffic control problem, namely lane occupancy.

Mr. W. K. Campbell, International Business Machines Corporation, was interviewed relative to a new system, Computer Real Time Control of Traffic, developed by his company and heretofore not available in published form.

Mr. L. Casciato, Chief Engineer, Traffic Research Corporation, Limited, Toronto, Canada, was contacted because of the test program which he is conducting in Toronto involving centralized traffic signal control by a general purpose computer. This is one of the few locations where a pilot operation has been in use for a period of time and where preliminary test data were available for evaluation.

Mr. Robert S. Foote, Manager, Tunnels and Bridges Research Division, The Port of New York Authority, New York, New York, was contacted because of the continuing research performed by his staff in the field of computer control of traffic control systems.

Mr. D. L. Gerlough, Head, Traffic Systems Section, Thompson-Ramo-Wooldridge, Inc., Canoga Park, California, was contacted because of the extensive work that he has performed in the field of Intersection Traffic Control, Computer Use for Traffic Control and in the use of computers for simulation of traffic in signalized intersections.

Mr. Edward Gervais, Traffic Research Engineer, Michigan State Highway Department, Lansing, Michigan, was interviewed because of his experience in this field, particularly in view of his work in connection with the John Lodge Expressway, Detroit, Michigan, and his experimentation with a computer controlled, single intersection in Lansing, Michigan.

Mr. Adolf D. May, Jr., Director, Expressway Surveillance Project, State of Illinois, Department of Public Works and Buildings, Chicago, Illinois, was interviewed because of his long experience in the field and his recent work with the Congress Street Expressway, Chicago, Illinois.

IV. DEFINITIONS OF TERMS USED

Analog computer. The analog computer is a type calculating machine that operates with numbers represented by directly measurable quantities, such as voltage or resistance. There is a direct correspondence or analogy between the quantities undergoing calculation and certain electrical quantities existing at various points within the computer.

Digital computer. The digital computer operates with numbers expressed directly in a decimal, binary or other mathematical form. The items of data are represented by coded combinations of signals in which each signal may exist in one of two discrete conditions.

Arterial. An arterial route is one designed to accommodate through traffic.

Cycle. A traffic signal cycle is the number of seconds required for one complete sequence of signal indications.

Offset. The offset in a traffic control signal system is the number of seconds that the green signal indication appears at a given signal indicator at a specified reference time.

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Phase. A traffic signal phase is the total time interval allowed for any one direction of movement or for movement in any two opposite directions. This includes the green interval during which movement is permitted and the clearance interval during which traffic is warned to stop.

Split. A traffic signal split phase is the splitting of one or more of the normal phases to accommodate heavy left turning movements. Normally similar indications for opposite approaches are arranged to be contrary for short intervals to permit traffic left turns. It is accomplished by either an advanced or a delayed green indication.

Shock waves. Shock waves are one of the factors which interfere with efficient traffic movement. They are periodic reductions in the flow and speed of traffic along the roadway.

Simulator. A simulator is a means of representing real phenomena with other characteristics. It is based on a system of mathematical and logical relationships.

Traffic control system. A traffic control system consists of two or more signal installations on a common street which are interconnected and controlled to provide an efficient flow of traffic.

IV. ORGANIZATION OF THE REMAINDER OF THE THESIS

In Chapter II, an analysis of traffic control systems is developed. The discussion of the systems currently employed include the following: (1) historical development, (2) traffic officer control, and (3) traffic control signal operations, which include systems operation, simultaneous operation, alternate systems, fixed time operation, simple progressive system, flexible progressive system and traffic actuated control.

In Chapter III, a descriptive study and analysis of computer controlled traffic systems is made. This includes a discussion of the following: (1) computer real-time control of traffic, (2) automatic flow control of traffic, and (3) centralized traffic signal control by a general purpose computer.

In Chapter IV, a comparison of selected factors of the computer controlled traffic systems is made. This includes a discussion, analysis and comparison of the following factors: (1) detection devices, (2) methods of processing input/output data, (3) control measures activated, (4) reaction time, and (5) degree of human control required.

Chapter V contains the conclusions and recommendations drawn from the descriptive study and the comparison of the selected factors. Recommendations as to additional areas requiring further research and analysis are proposed.

CHAPTER II

ANALYSIS OF TRAFFIC CONTROL SYSTEMS

I. EVOLUTION OF TRAFFIC CONTROL SYSTEMS

The earliest traffic control system can probably be ascribed to the ancient Romans. They established one-way traffic flow on selected streets, special off-street parking and specified hours for unlimited use of the city streets. The first traffic regulations were posted in Babylon about 2000 B.C. Moving up through the years we find pavement lane markings making their appearance in Mexico City around 1600 A.D. The earliest efforts at police control of traffic were in New York City in 1850. In 1904, William Phelps Eno initiated traffic survey methods in dealing with traffic control problems. In 1916, E. P. Goodrich employed Speed and Delay studies in working with the problem of traffic congestion.[1]

Modern electric traffic control signal devices, as opposed to signs, markers and other devices, are of rather recent origin. They may be considered descendants of the manually operated semaphores which were first used in 1910.

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[1]Henry K. Evans, Traffic Engineering Handbook (second edition; New Haven: Institute of Traffic Engineers, 1950), pp. xi-xii.

Detroit set the pace in the use of semaphores, eventually fitting them with colored lanterns for night time use. The first recorded electric traffic signal control was employed for a brief period in Cleveland, Ohio, in 1914. This system utilized four red signal lights on the near corners and four green lights on the far corners of the intersection. The red and green lights operated alternately by means of a crude timing device. This traffic signal control system, which enjoyed only a brief operational period before being replaced by the system of police officer control, was invented by James Hoge in 1913. This crude system was the progenitor of the three color light signal which first appeared in New York in 1918, and then throughout the rest of the country in the 1920's. The United States led the rest of the world in the development and use of traffic control signal devices. They did not come into general use in Germany until 1926 and in England until 1928.[2]

Preceding the use of traffic control signals was the short era of traffic towers. These were first used in Detroit in 1916 and later in New York City. An experiment which was doomed to failure was attempted in Philadelphia in 1924, when large searchlights were mounted atop the city hall building to control street traffic over a wide area.

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[2]J. T. Hewton, Traffic Signals: An Outline of their History and Function (Toronto, Canada: Department of Traffic Engineering, 1957), par. 12.00.

The overwhelming confusion and congestion that resulted from this experiment ended the use of a single signal for large areas. It did, however, indicate the awareness of a need for the coordination of signals over large areas. Between 1922 and 1927, the traffic towers and traffic signal devices fought for supremacy in the field of traffic control. By 1930 the traffic tower had all but disappeared.[3]

The first interconnected traffic signal system was put into use in Salt Lake City, Utah, in 1917. In 1922, E. P. Goodrich publicly proposed a plan of timing signals for progressive traffic movement. It is reasonable to assume that the first Time-Space diagram for progressive traffic control systems was drawn up between that date and 1927. The first traffic actuated signals made their debut in New Haven and East Norwalk, Connecticut, and Baltimore, Maryland, in 1928.[4]

Although various means of controlling and regulating traffic have been in effect for many centuries, the use of signal control devices is of recent origin. Unfortunately, the development and sophistication of these devices has not kept pace with the rapid growth in the number of automobiles using the highway and street systems.

II. TRAFFIC SYSTEMS CURRENTLY EMPLOYED

Traffic officer control. The methods of employing

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[3] Ibid. [4] Evans, op. cit., p. xii.

police officers for traffic control purposes varies according to the type and location of the city, the surrounding area, the layout of the streets and the type vehicular traffic encountered. Other factors which affect the type of control exercised are the policies of the department, the number of personnel available for traffic control duties and the quality of the personnel assigned. Although many variations exist, there are certain basic requirements that are common to all departments. These are to keep traffic flowing smoothly and as rapidly as is consistent with safety.

Another similarity in basic approach, although not in the specific method of employment, is the method of relieving traffic congestion or traffic jams. The method, simply stated, is to locate the source of the trouble and take corrective action. At this point we find a great variation in the means employed to relieve congestion and reduce traffic jams. One man is rarely able to handle a traffic congestion area. When several officers are assigned to a small geographic area, as is common in our larger metropolitan areas, or when spotter vehicles and aircraft are used in conjunction with traffic control personnel, then these different agencies attempt to coordinate their activities to keep traffic flowing through a larger area. This system of control, regardless of the number of men and the amount of equipment employed, has certain limitations. Foremost among these is the limited distance that each officer can see.[5] In many instances his view of approaching traffic is limited to one city block and often less. His knowledge of what is transpiring elsewhere in the system is severely restricted. Even if several officers are in the immediate visual range of each other, their ability to recognize an abnormal traffic situation is usually after the situation has developed. The time required to contact the other officers, coordinate their actions and initiate corrective action limits their effectiveness to reducing existing situations rather than preventing situations from occurring. Again these several officers working together take corrective action without knowing what effect their actions will have on other portions of the traffic system.

Airborne surveillance. The use of airborne spotters in conjunction with traffic control personnel has relieved this problem to a limited degree. The observer is able to see the traffic pattern in all directions, recognize emerging conditions, and in turn notify traffic personnel of impending or developing trouble areas. Here again there is a time delay in recognizing the situation, reporting the situation and the subsequent reaction to the situation. The time factor in reacting to the situation is a critical limitation of the efficiency of the traffic officer.[6]

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[5] Robert S. Foote, Development of an Automatic Traffic Flow Monitor and Control System (New York: The Port of New York Authority, 1961), pp. 4-5.

[6] Ibid., p. 4.

In resolving a traffic problem the traffic officer will normally perform the following pattern of actions:

1. Detection of a situation by sight or hearing.

2. Decision as to whether corrective action is required.

3. Confirm the existence of the problem.

4. Call for assistance or alert others (police or drivers) of the problem, if necessary.

5. Divert, stop or speed up traffic to eliminate the problem.

6. Assistance to the elements causing the problem.

7. Restore traffic to its normal pattern.

These seven steps can be broken down into three main components--the time needed to detect the problem, the time needed to respond and the time needed to restore normal operations. This is a relatively slow process and normally takes place after the problem has developed. Thus we are reducing an actual situation rather than preventing a potential situation.[7]

Another limitation not usually considered is the reduction of the effectiveness of police officer control by the inability of the vehicle operators to see the police officer clearly and to understand the instructions or changes

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[7] Ibid., pp. 6-9.

of instructions given.[8]

Television surveillance. Of fairly recent origin is the use of television surveillance equipment in traffic control work. This has often been erroneously described as an automated traffic system. Actually, the use of television can be grouped with devices such as vehicles and aircraft. It is primarily a means of extending the traffic officers' vision. It is particularly helpful in areas where, during peak traffic periods, interference to the traffic flow would be reflected over large areas. Continuous surveillance would permit the police to take corrective action in a shorter period of time. This has been aptly demonstrated on the John Lodge Expressway in Detroit, Michigan, where a series of TV cameras transmit a continuous series of pictures of traffic conditions to a master control room. The TV monitors are scanned by traffic personnel, who make decisions, based on the traffic flow, to raise or lower speed limits or to restrict traffic in certain lanes. They have the necessary centralized controls to effect changes in the control signals along the route. This system would best be described as a semi-automated system since the

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[8]Joseph B. Bidwell, Control Problems of Automatic Highways, Conference on Electronic Controls and Traffic Safety (New York: Safety Education Project, Teachers College, Columbia University, 1958), p. 4.

decisions are made by humans.[9]

<u>Existing traffic signal systems</u>. The flow of traffic on city streets is generally limited by the capacity of intersections. Where traffic control requires the installation of traffic signals, the intersection capacity is inherently reduced by the ratio of the red signal time to the total traffic signal cycle. Further reductions in capacity result from the time required to get a traffic stream moving once it has been stopped by turning movements, interference and cross traffic. By virtue of these conditions there is thus a boundary to the effectiveness of a traffic signal system. Existing traffic signal systems, however, are in many cases a long way from this boundary, and thus can be subject to substantial improvement.[10]

Although crude techniques are available for handling traffic along a thoroughfare or within a network, still a large proportion of traffic signals throughout the United States are essentially controlling traffic on an individual-intersection basis. In the city of Los Angeles less than 20% of the traffic signals are connected in such a manner

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[9] Information obtained from personal correspondence and interviews with Mr. Arthur C. Gibson, Traffic Engineer, City of Detroit, Department of Streets and Traffic, Detroit, Michigan.

[10] D. L. Gerlough, "Some Problems in Intersection Traffic Control," <u>Theory of Traffic Flow</u> (Proceedings of Symposium on Theory of Traffic Flow held at General Motors Research Laboratories, December, 1959), p. 10.

that they may be maintained in an appropriate time relationship to other nearby traffic signals.[11]

Grunow noted that the movement of traffic on urban streets is dependent upon the degree of congestion or delay. Traffic signal delay is the major cause of congestion.[12]

Traffic control signal operations. Traffic control signal operation may be classified according to the number of alternating traffic movements permitted, the methods of time apportionment, and the time relationships between the start of the green intervals at adjacent intersections on a common street. In general, the simplest mode of operation which will handle the required traffic movements in safety will be the most efficient and should always be used.[13]

System operation. A system operation results when two or more signal installations on a common street are set up and timed in such a way that the appearance of the common street green indication at one intersection will be followed at a definite repetitive time interval by the

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[11] Ibid., pp. 10-11.

[12] R. N. Grunow, "Vehicle Delay at Signalized Intersections as a Factor in Determining Urban Priorities," Highway Needs Studies, Highway Research Board Bulletin No. 194 (Washington, D.C.: National Academy of Sciences-National Research Council Publication, 1958), p. 42.

[13] J. T. Hewton, Traffic Signals (Toronto, Canada: Department of Traffic Engineers, 1957), par. 14.00.

appearance of the same indication at the next signalized intersection. In general, all signals within 1200 feet of each other on the same street should be formed into a system, since otherwise delay and inconvenience will probably result for traffic using the street.[14] The time lag between the appearance of the common street indications at adjacent intersections is known as the offset and the relationship between the offset and the overall traffic cycle length determines the nature of the resulting system. System operation may be established and maintained in two ways, namely: non-interconnected and interconnected systems.

Simultaneous system. In this system the offset is zero and all signals show the same indication to the common street at the same time and therefore exactly the same phase times must be used at every installation forming a part of the system. In its simplest form one controller may be used to operate a series of signals.[15] This is not recommended since any defect or breakdown will render the entire system inoperative.

The disadvantages of this system are:

1. Simultaneous stopping of all traffic along a common street prevents continuous movement and results in high speed between stops, but low overall speed in the system.

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[14] Ibid., par. 14.40. [15] Ibid., par. 14.41.

2. Cycle lengths and interval proportioning are usually determined by the requirements of one or two major intersections in the system. This creates inefficiency at the other intersections.[16]

Alternate system. In this system the offset is one-half the cycle length and therefore adjacent signals show opposite indications to the common street at the same time. This system can provide for continuous through movement if all conditions are favorable.[17]

This system has the following disadvantages:

1. Equal phase intervals are required for both the main and side street traffic which is likely to be inefficient at most intersections.

2. It is not adaptable to streets having blocks of unequal length.

3. It reduces the road capacity during periods of heavy traffic since the rear part of a vehicle platoon clearing one signalized intersection will be stopped by the next signal in the series when the signal changes.[18]

Fixed time operation. In this system the signal indications are switched on and off in a predetermined, repetitive sequence. The length of each interval and the

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[16] Evans, op. cit., p. 229.

[17] Hewton, op. cit., par. 14.42.

[18] Evans, op. cit., pp. 229-230.

time required for a complete cycle are always the same, except that in modern expansible equipment these lengths can be varied at pre-set times of the day. This mode of operation has the advantage that the control unit is sturdy and relatively simple while the sequence of signal indications can be quickly and simply changed to allow for additional phases. The units may also be simply and positively interconnected for systems operation without the need for any additional or special equipment.[19]

The principal disadvantage is the fact that short term volume variations cannot be readily allowed for and that undue delay result for main street traffic during low volume periods. Stopped time delay for any vehicle which is required to stop is much greater with fixed time control than with any other system.[20]

The motorist views this system only as it produces delays to his travel. The control cycle is changed without regard to the delay being produced or the amount of traffic actually present. That is, the control system is not responsive to the needs of the traffic actually present.[21]

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[19] Hewton, _op_. _cit_., par. 14.21.

[20] Wayne N. Volk, "Effect of Types of Control on Intersection Delay," _Highway Research Board Proceedings_, Vol. 35 (Washington, D.C.: National Academy of Sciences-National Research Council Publication, 1956), p. 523.

[21] D. L. Gerlough, "Some Problems in Intersection Traffic Control," _Theory of Traffic Flow_ (Proceedings of Symposium on Theory of Traffic Flow, held at General Motors Research Laboratories, December, 1959), p. 11.

Simple progressive system. In this system the same cycle length must be used at all signalized intersections, but the offset bears no fixed relationship to the cycle length as it is adjusted so that a vehicle entering the system at one end will be able to pass through all intersections without being stopped. The offset between adjacent intersections therefore depends on their distance apart and the permissible vehicle speed. The time allotted to the various phases at different intersections can vary, though naturally the shortest time given to the common street will determine the maximum number of vehicles which can make a non-stop through movement.[22]

A simple progressive system is far more efficient than those previously described but is normally only suitable for use on one-way streets having reasonably constant traffic volume and vehicle speed.[23]

Flexible progressive system. In this system the same cycle length must be used throughout but the phase time can be varied in accordance with traffic requirements and the offsets can be varied to allow for unequal signal spacing. The cycle, phase time and offset can be independently or collectively varied to suit different traffic conditions at different times of the day. Thus for a normal

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[22]Evans, op. cit., p. 230.

[23]Hewton, op. cit., par. 14.43.

traffic artery, the cycle lengths, phase times and offsets can be set up and automatically selected for:

1. Morning peak hours with offsets favoring inbound movements.

2. Normal day conditions with offsets arranged to give the best possible two-way movement.

3. Evening peak hours with offsets favoring outbound movements.[24]

This type system must be of the interconnected type with a central master controller supervising all time relationships and coordinating all cycle function changes. Modern expansible equipment can provide a maximum of three different cycles, with each having three different offset positions, thus providing nine combinations of cycle and offset timing which may be automatically selected for use at various times of the day.[25]

This system has the following advantages:

1. Continuous movement of groups or platoons of vehicles is possible with reduced delay and at an average speed as planned for the system.

2. Platoon movement tends to form gaps which may be utilized for safe vehicular or pedestrian crossing at non-signalized intersections.

3. High and low speed travel is discouraged

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[24] _Ibid._, par. 14.44. [25] _Ibid._

since both would be penalized by delay at the next signalized intersection.[26]

Each of the described systems has certain advantages and disadvantages. One disadvantage which is common to these systems, but which has not been discussed individually since the present day equipment is not designed to cope with the problem, is that the systems are not responsive to traffic conditions at any given moment. The cycle lengths are set for a particular period based on what occurred in the past, not what is occurring at the instant time. If the traffic conditions affect the pre-planned patterns to the extent that a change in the system is required, then several courses of action are available to effect the change. The police officer on duty may do one of the following:

1. Switch the signals off completely and manually direct traffic until the situation is back to normal and then restart the signals.

2. Switch the lights to flashing operation and accept the additional delay and congestion until the traffic volume decreases enough to resume normal operations.

3. Manually operate the signals and trust his own judgment to recognize immediate traffic requirements and arrange the cycles accordingly.[27]

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[26]Evans, op. cit., pp. 230-232.

[27]Hewton, op. cit., par. 16.00.

As can be seen, these courses may reduce the problem but the time required to do so may be extensive. The end result is traffic control signals which are designed to reduce the degree of human control required for this function eventually are dependent on that human control when conditions differ from those which the system was preset to accommodate.

Traffic actuated system. This system acts in accordance with traffic demand. The length of each interval and of the overall cycle are almost infinitely variable. The principal advantage of this system is that delay, especially at minor intersections, is held to a minimum. The principal disadvantage is that each unit acts independently without regard or knowledge as to what is transpiring elsewhere in the system. This individual reaction to traffic demand creates as many delays elsewhere in the system as it eliminates at its own location.[28] Although this system is operated on a traffic demand basis, fixed time signals which are properly coordinated can result in less overall delay within the entire system than the individual traffic actuated signals.[29] This is not due to the system itself, but rather to the manner in which the agency operates it.

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[28]Evans, *op. cit.*, pp. 257-268.

[29]Lewis, *op. cit.*, p. 3.

Operation of intersections without controls of any type would result, in theory, in the least vehicle delay. From this idea of minimum control the traffic actuated system could be more efficient than fixed time controls. In either system, the delay to vehicles on the side streets would be approximately the same.[30]

Thus we have briefly examined the systems currently employed in controlling traffic. Each system has its own advantages and disadvantages. Each was designed with a particular function in mind. Each was and is installed at considerable expense. The remarkable and awesome growth of vehicular traffic in and through our metropolitan areas could not have been foreseen or predicted when these systems were designed and installed. This is also true of the planning and construction of arterial networks on which traffic patterns must be based and upon which control systems must be superimposed. That the systems are not adequate to perform their intended function is apparent when one observes the congestion that metropolitan drivers have been forced to accept as an inevitable happenstance of progress.

Present systems are characterized by the absence of feedback loops; that is to say, information is not fed back into the equipment relative to traffic density, lane

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[30]Volk, op. cit., p. 533.

occupancy or delays and congestion. The equipment is pre-set to a certain cycle and remains there until re-set. It does not have the capability of analyzing current traffic demands and re-setting the signal cycles accordingly. The lack of responsiveness to immediate and changing conditions is a primary disadvantage of existing traffic signal systems and is directly caused by this open loop system. A closed loop or feedback capability would provide a traffic system with the capability of receiving information relative to traffic delay or congestion and vehicle density. With this information, a fully actuated system would provide maximum efficiency in maintaining optimum traffic flow.

CHAPTER III

COMPUTER CONTROLLED TRAFFIC SYSTEMS

In discussing the use of computer controlled traffic systems it is necessary to understand the functions and limitations of the electronic computer.

A computer is a highly complex electronic machine which is capable of performing many complex computations in a very short period of time. Basically it consists of four logical units: memory, input/output, arithmetic logic, and control. The memory unit is the location where information is stored. Vast amounts of external information can be accepted and stored for indefinite periods of time. This stored information can be continuously up-dated as changes occur. The input/output unit is the medium through which information is transmitted to and from the computer. The input portion performs functions very similar to the sensory organs of man. Input devices may take various forms, such as: punched cards, paper tape, magnetic tape, typewriters and other instruments.[1] In traffic control systems detectors are the input devices. Output devices take the same general form as input devices with the exception that

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[1]Franz L. Alt, Electronic Digital Computers (New York: Academic Press, Inc., 1958), p. 26.

in traffic control systems the output would be reflected in the control devices actuated. The arithmetic logic unit performs the function of the basic arithmetic operations and logical manipulations. The control unit coordinates and controls the other units and performs the integrated functions of the computer.

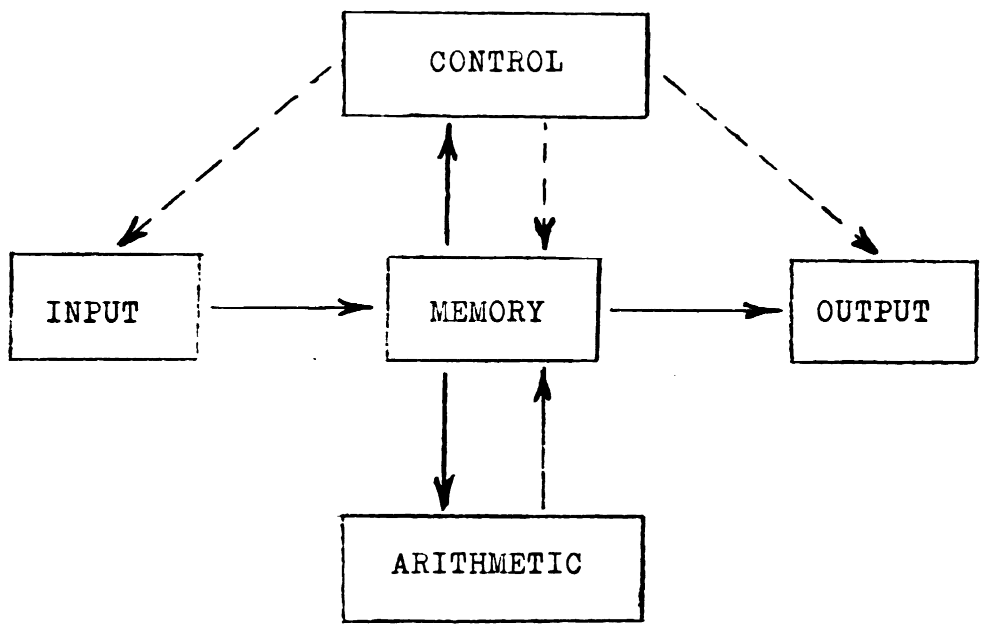

FIGURE 1

SCHEMATIC DIAGRAM OF ELECTRONIC COMPUTER FUNCTIONS

The electronic computer can perform many operations in rapid time, but it has limitations. It will do only what it is programmed to do. Man must put the basic information into the computer either through his own direct efforts or through the use of sensor equipment. This information serves as the base from which the computations, comparisons and decisions are made. In effect, the computer can do only what man can do, except that it is able to do these things faster and with less chance of error.

Computer real-time control of traffic.[2] This system envisions a traffic control system that is completely responsive to traffic demand rather than being based on a pre-set, fixed time operation or independent traffic actuated systems. To illustrate the need for this type of control, picture an intersection where a long stream of vehicular traffic is suddenly stopped by a red traffic signal. There are no vehicles on the cross street taking advantage of the green signal. The light has turned red for no apparent reason, because there was no demand from the cross street for traffic to go across the intersection. The reason for this senseless delay is fairly obvious with present day methods of control. There is a set time control on the traffic signal. In other words, there are a certain number of seconds for the red, amber and green signals.

Real-time traffic control is designed to eliminate this needless delay. If traffic is heavy on the artery, real-time control would not change the traffic signal unless there was a demand from the cross street. There is a

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[2] International Business Machines Corporation, Computer Real-Time Control of Traffic (A presentation made to the Commissioner of Traffic, Cleveland, Ohio, June 4, 1962).

maximum cycle length established for the signal lights, since it would not be desirable to have a signal light showing one phase for extended or indefinite periods. Nor would it be desirable to have the phase changing every few seconds just for the sake of change. In effect, what the system will do is change the timing of any signal or series of signals in response to demands made on the system. Depending on the number of vehicles at each intersection and depending upon the other lights in the system, the computer would calculate the time the light should be red or green at different times of the day. This may vary at every instant of the day.[3]

Simulation. The system under discussion is not an operational system in the sense that it is actually controlling traffic. It is a system devised through simulation of actual conditions by means of an electronic computer. The purpose of simulation on a computer is the experimental determination of phenomena which are too complex to study analytically and which may not be conveniently studied empirically in a real life situation.[4]

In the past, efforts to solve a traffic problem have

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[3] Ibid., p. 2.

[4] Aaron Glickstein, Leon D. Findley and S. L. Levy, "Application of Computer Simulation Techniques to Interchange Design Problems," Freeway Design and Operation, Highway Research Bulletin No. 291 (Washington, D.C.: National Academy of Sciences-National Research Council Publication, 1961), p. 146.

been by analysis and trial, analysis being a mathematical expression used to represent a traffic process and then manipulating it to determine the values to be used in changing to better conditions. Trial involved a change in a real life traffic situation. Simulation is a combination of both methods. It permits an attack on the most complicated of processes which the analysis method did not. It does not affect traffic until a solution has been reached, unlike the trial method which may disrupt the traffic system completely before a final solution is reached.[5] Employing simulation techniques avoids the expense of installing new equipment or modifying existing equipment to test a proposed system. As can be seen, if the proposed system is not feasible, then, through simulation, a new system can be developed without additional changes in the existing system. Simply stated, the simulation model duplicates in a digital computer a real life situation. The concept of movements and delays is the central feature of this simulation.[6]

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[5]Harry H. Goode, Carl H. Pollmar and Jesse B. Wright, "The Use of a Digital Computer to Model a Signalized Intersection," Highway Research Board Proceedings, Vol. 35 (Washington, D.C.: National Academy of Sciences-National Research Council Publication, 1956), p. 549.

[6]D. L. Gerlough and F. A. Wagner, Jr., Simulation of Traffic in a Large Network of Signalized Intersections, Paper to be presented at the Second International Symposium on Theory of Road Traffic Flow. (Sponsored by the British Road Research Laboratory, London, England, June 25-27, 1963), p. 2.

The simulator can be used to investigate different controls of traffic signals. In other words, depending upon demand which is the number of vehicles at each approach to a signal light and depending upon the other lights in the system, the computer will calculate the time the light should be red or green at different times of the day. There will be no fixed time for red, amber or green on a particular light, rather it may vary at every instant of the day. Instead of going out to a location and hooking up detectors and vehicle counters and tying them into the computer, vehicle counts are taken along the route to be controlled. This information is used in the computer simulation so that the computer calculations correspond with the actual traffic situation in the selected area.[7]

In the typical urban area the settings of cycle length, split and offset are determined not from the number of vehicles on the street at any given moment, but rather from the number of vehicles that were on the street on the days the traffic was counted. With the exception of traffic actuated signals, present day systems do not respond to the second by second demands of traffic at each light. In fact, they are indifferent to the number of vehicles waiting at each intersection at any given moment. Real time control is designed to increase utilization of

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[7]International Business Machines Corporation, op. cit., pp. 2-4.

the intersection and thus reduce vehicle delay.[8]

System operation. In employing the traffic control simulator typical distribution of vehicle arrivals and different traffic signal control methods are applied for a geographic area and fed into the simulator. The consequences of signal timings and various vehicle arrivals are given in terms of a series of signal control decisions and resulting traffic flow (see Figure 2).[9]

The computer real-time traffic control system is basically divided into three logical functions. The first function is the real traffic generator. This generator may be based on random vehicle arrivals or from pulsed flows. The second function is the simulator. It computes the intersection outputs and queues in each arm of all intersections. The traffic patterns at all intersections at the end of each generation or other fixed period of time are determined. The results of this simulation are analogous to a motion picture taken from above, looking down at the entire traffic area system. Each generation resembling each frame of the film is a photograph of the continuous traffic flow. Therefore, the simulator treats the traffic flow as a series of discrete photographs. The third function is the control function which may contain any two types of control mechanisms. The first control

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[8]*Ibid.*, p. 4. [9]*Ibid.*, p. 7.

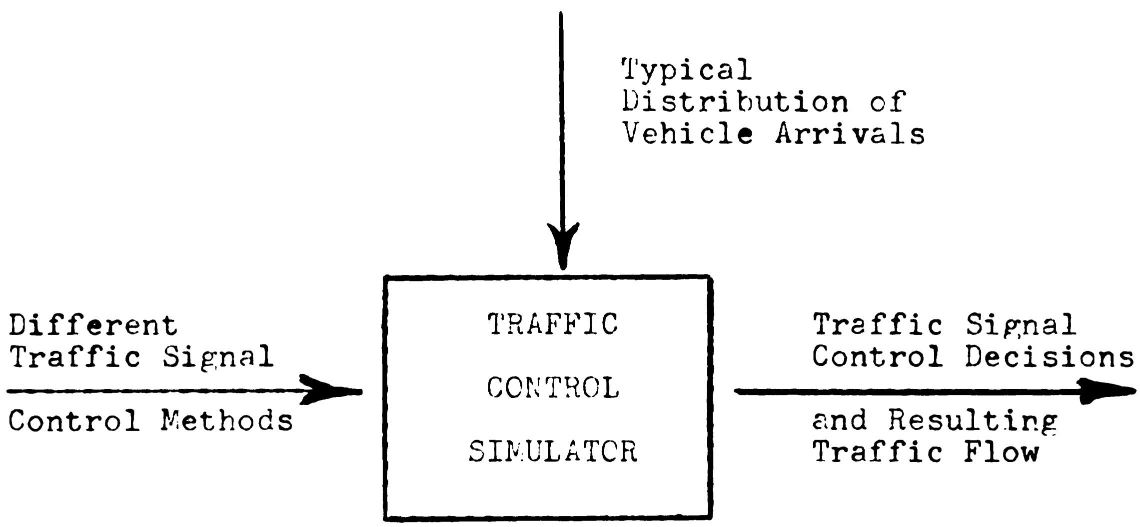

FIGURE 2

TRAFFIC CONTROL SIMULATION

mechanism being a real time adaptive feedback method in which the decisions are based on real-time queues which are weighted in relation to the cumulative green light signal time. The second control mechanism is the existing fixed time signal control system. The choice between the two methods of control is made by the "on" of "off" status of an external switch on the computer console. The computer makes the decision as to which control method will be employed. The results of the control function are merely a time sequence of reds and greens for each signal which, in the light of the traffic demand patterns, will determine traffic behavior (see Figure 3).[10]

The following specifications must be determined and inserted into the computer as the source input:

1. Road status
   a. number of lanes
   b. road width
2. Per cent commercial type vehicles
3. Per cent left turns
4. Intersection lane capacity
5. Green arrows
6. Initial number of vehicles in intersection lanes.
7. Arrival distributions

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[10] _Ibid_., pp. 8-9.

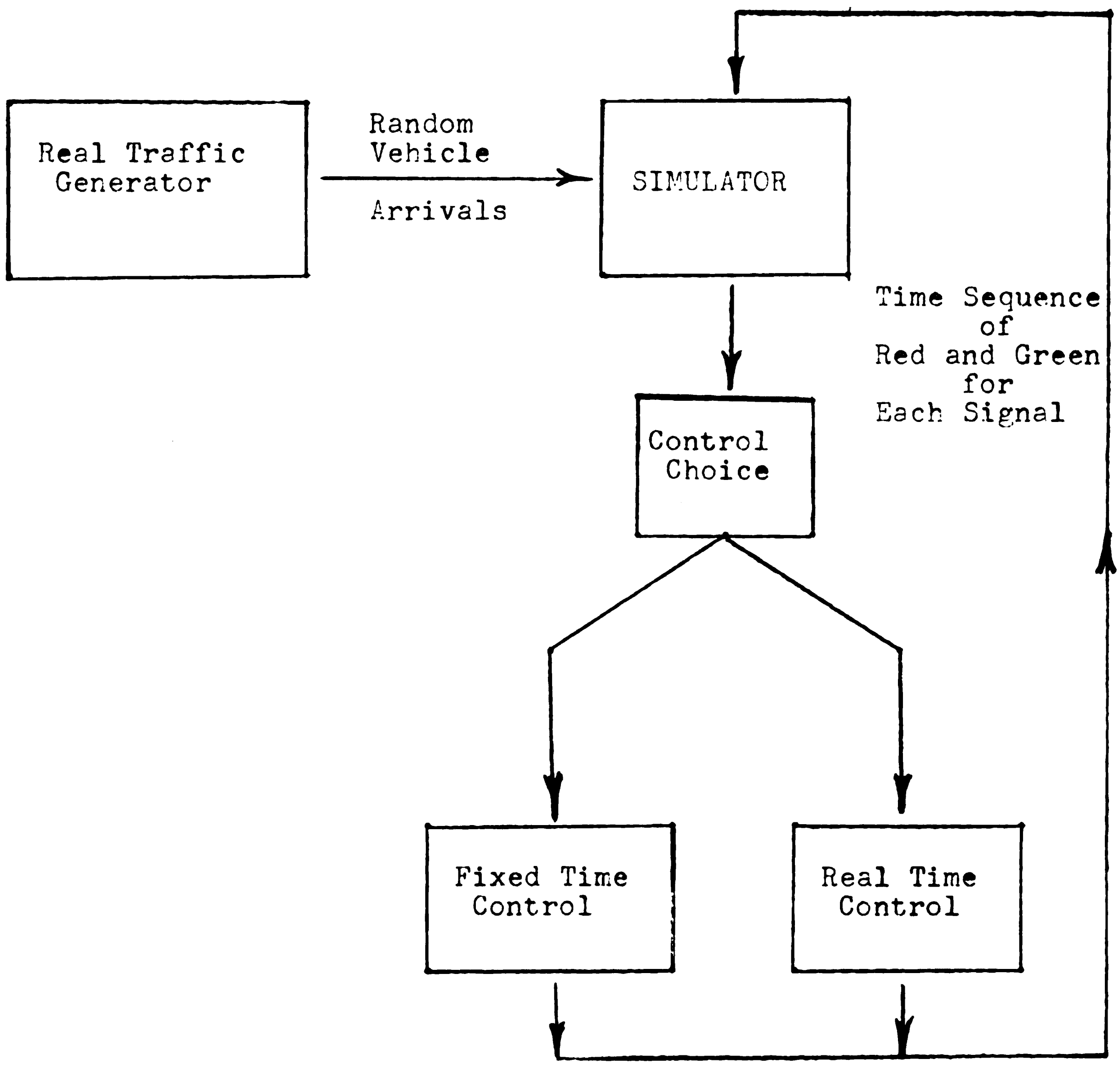

FIGURE 3

THREE LOGICAL FUNCTIONS OF THE TRAFFIC CONTROL SIMULATOR

8. Signal status
    a. green, amber, red
    b. elapsed time since last change
9. Traffic flow rate

The number of vehicles in each intersection lane, the signal change pattern and the total delay for the entire area system are provided as the simulation output.[11]

Detection system. The real-time computer system utilizes information from detectors that pick up vehicles leaving the intersections. The detection of vehicles is sensed by the computer through either a wire or radio communication link. Based on the vehicle count and speed information, the digital computer makes decisions as to what signals should be changed. The instruction to change is transmitted over the communication channel to the local intersection controller. Thus there is a closed loop control of intersections with the following sequence:

1. Detection
2. Communication
3. Computer
4. Local controller

The first step of the closed loop sequence is detection. The sooner that vehicles are detected before the next intersection, the more time there is available to

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[11] Ibid., pp. 9-11.

accomplish a change at the intersection. Vehicles should be detected as they leave the intersection as well as when they enter it. For intersections with special left turn lanes, the detector should be located much nearer the intersection since the vehicles that are crossing the intersection are going to be in motion while the vehicles in the left turn lane may be moving very slowly or stopped. In the case of vehicles going through the intersection, a non-presence type detector, e.g., radar and pressure road switch type detectors, would serve the purpose. For the turn lanes, a presence type detector, e.g., induction, sonic or infra-red type detector, would be required. The condition of traffic at the position in the street where the detector is to be employed will determine the type detector required.[12]

The detection devices that can be employed in this system are classified into two basic types:

1. Presence detectors which will detect vehicles at all speeds, including stopped vehicles.

2. Non-presence detectors which will not detect vehicles travelling at speeds less than 2 mph.

The detectors are further classified by their principle of operation.

1. The induction type detects only metal objects which, on passing over a loop of wire embedded in

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[12] *Ibid.*, pp. 13-15.

the surface of the pavement, cause the inductance of the loop to be changed and thence recorded.

2. The infra-red type detects any object which passes through the intersection line of the plane of infra-red transmission and the acceptable plane of the infra-red receiver.

3. The sonic type detects the delay time between the time a speaker transmits a tone and the time a receiver hears the reflected tone. The shorter the elapsed time, the taller the detected vehicle. This is the only detector which can classify vehicles by size.

4. The radar type detects the doppler phase shift in the energy wave that is beamed at the oncoming traffic. A vehicle has to be travelling at a speed greater than 2 mph to cause a phase shift great enough to be detected.

5. The pressure road switch detects the pressure of an automobile's tire, causing a high rate spring to deflect and make an electrical contact. The road switch is embedded in the pavement in a long square-ended prism. The unit is encased in a rubber-like potting compound.

6. The earth magnetic type detects the change in the earth's magnetic field with a tightly wound coil installed below the pavement. A car passing over the coil distorts the magnetic field.

7. The photoelectric type detects the absence

of light reflected from a mirror positioned on the other side of the road.

8. The permanent treadle type detects the pressure of a tire on an 8"-wide contact plate. By deflecting a high rate spring beneath the plate, an electrical contact is made. The permanent treadle type uses the same principle as the road switch type; however, the treadle type is much larger.

Studies indicate that the radar type detector would perform the required tasks at the lowest cost, although it has the disadvantage of not detecting very slow moving or stopped vehicles.[13]

Reaction time. By definition, when a vehicle is under a detector and the detector causes a relay control to close, the closed contact condition is called the "on" state. When the vehicle has left the detection zone, the relay contact opens. This condition is called the "off" state. The computer determines the number of vehicles that have passed under a detector by rapidly scanning the detectors and noting the number of detector "on-off" changes that have occurred, with the contact sense capability of the computer. If the sampling rate is rapid enough, so that one complete scan of all the detectors will occur in less time than either an "on or off" state, then there is an

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[13] Ibid., p. 15.

assurance that the computer will avoid counting two vehicles as one or one vehicle as two.[14]

In order to determine the time required to sense all of the detectors in a system, the "on and off" times that are typical for the type detectors employed must be determined. For induction type detectors, the "time on" length equals the length of the vehicle plus the effective detector length. For sonic, radar and infra-red types, the "time on" length equals the length of the vehicle plus the small effective detection pattern width. For the road switch type, the "time on" length equals the length of the tire contact patch plus the road switch effective width. The "time on" length is a function of the time on and the vehicle speed. The "time off" is a function of the time on length, the vehicle spacing and the vehicle speed.[15] The minimum time interval for a change of state for the detector has been determined to be five milliseconds (5 ms.). The computer employed in this system has the capability of performing 25,000 detector point scans per second. This would average out to a system whereby one computer could effectively control 30 signalized intersections, each having 4 detectors. This would include a range of accurate detections up to speeds of 68 mph.[16] If speed limits were

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[14] *Ibid*. [15] *Ibid*., p. 16. [16] *Ibid*., p. 32.

higher than this figure, it would necessitate reducing the number of controlled intersections. Conversely, lower speeds would increase the number of intersections that could accurately be controlled by a single computer, since the lower speed would permit a greater time gap for the computer to scan the detectors. In addition to scanning the detectors, the computer also has the capability of processing a control program at the same time. Thus the computer is scanning the detectors and recording the number, direction and speed of the vehicles within the system and at the same time it is processing, based on programmed data, the sequencing of traffic signals to provide the optimum traffic flow.

Fail-safe operation. The computer real-time system is designed to overlay an existing traffic signal control system. This provides a minimum installation expense. Present traffic signal devices operate on a three or four wire connection depending on whether the signals are controlled from a central master controller or by local intersection control. If the hook-up is a local intersection control, then the four wire lead is interconnected to the computer or if it is a central master control, then the three wire lead is interconnected. With this interconnection, the intersection controllers are operated from the computer. If the computer fails, then the existing timing dials at each controller or at the central master controller would still operate the traffic signals, since the original system is not altered. This also permits the option of discontinuing computer control during low vehicle volume hours, so that the existing control system can operate without requiring adjustments or secondary installations.[17]

The results of the simulation of the traffic control model for the Willow Freeway, Cleveland, Ohio, indicated that the existing traffic control system resulted in a utilization of from 40-60% of road capacity. The real time computer control system would provide a utilization of 90% of capacity.[18] This increase of road capacity utilization would result in a 50% reduction in vehicle delays. This would seem to justify its installation even if no other benefits were accrued. In addition to the reduction of vehicle delay, real-time control of traffic provides the following benefits:

1. It delays the time when street and roadway expansion becomes necessary. This is realized from the increased utilization of existing road capacity.

2. It identifies specific areas which need improvement and then simulates different types of improvements to determine which is best. By simulating proposed improvements, major changes, such as installation of one-way streets, additional control signals, installation of

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[17] _Ibid._, pp. 24-26. [18] _Ibid._, p. 23.

special traffic lanes or major construction can be programmed to determine if they will meet the requirements. Future improvements and long range planning requirements can be predicted by the computer.

3. It assists in street layout planning by providing the means to simulate various traffic plans to determine both their traffic handling capability and also the effect it would have on adjoining areas.

4. City evacuation plans can be expedited by computer control. It is questionable if personnel assigned to direct evacuation traffic can or will be able to remain at their posts. The computer can be programmed to provide the best traffic flow pattern in accordance with a pre-determined evacuation plan.

5. It records changes of traffic patterns. The computer has the capability of providing a permanent "write out" record of information relative to traffic patterns, vehicle density and speed and traffic trends. This information can be utilized in future improvement planning.

6. It assists in routing emergency type vehicles. By sectioning off the city and preparing computer sub-routine programs, the computer has the capability of selecting the shortest and quickest route to the emergency route and controlling the traffic signals along the route to permit emergency vehicles to travel without interruption or delay.

7. It reroutes traffic due to accidents or other situations. By installing additional motorist aids, such as: directional arrows and electrical detour signs, at key intersections, the computer has the capability of recognizing abnormal conditions within the traffic system and then actuating the directional or detour devices, to reroute traffic around the abnormal area. It would maintain this detour until the situation was resolved and then revert back to the normal traffic pattern.[19]

Evaluation of the system. Since this system is a simulation model, it is difficult to assess its actual capabilities.[20] The principle of the system is logical and, within limits, feasible. As Gerlough noted, while field data were not available with which to make quantitative comparisons with operational systems, the results attained were qualitatively consistent.[21] That is to say that simulation models, based on different traffic situations, volumes, speeds and locations, are consistent in the results that can potentially be obtained. It is anticipated that real-time control of traffic will appreciably reduce vehicle

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[19]Ibid., pp. 19-22.

[20]See pages 38-39 for detailed discussion.

[21]D. L. Gerlough, "Simulation of Freeway Traffic by an Electronic Computer," Highway Research Board Proceedings, Vol. 35 (Washington, D.C.: National Academy of Sciences-National Research Council Publication, 1956), p. 547.

delay and thus relieve traffic congestion. The estimated efficiency of a 50% reduction in traffic delay is questionable, since the results of simulation have yet to be compared to the actual traffic process.[22] Although the computer has the capability of recognizing major trouble areas and changes in traffic flow, it does not have the sophistication, as yet, of recognizing and reacting to the minor causes of delay. Specifically, the instances where a vehicle slows down to observe happenings along the sidewalk or in store windows, or stops to discharge a passenger in the middle of the street, or to slow down when undecided as to which direction to follow, are as yet beyond the capability of the computer to anticipate, recognize or react to. For these reasons, it appears that a more probable reduction of vehicle delays would be in the range of 10% during peak periods and 20% during mid-day off-peak periods.[23] This is not to depreciate the potential capabilities of the system but rather to state a practicable range of capabilities in view of the present day development of computer systems.

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[22]Perchonok and Levy, op. cit., p. 518.

[23]D. L. Gerlough and F. A. Wagner, Jr., Simulation of Traffic in a Large Network of Signalized Intersections (Paper to be presented at the Second International Symposium on Theory of Road Traffic Flow, Sponsored by the British Road Research Laboratory, London, England, June 25-27, 1963), p. 13.

Automatic flow control of traffic.[24] This system is based on the principle that, in considering the flow of traffic along an arterial, optimum behavior results when the traffic moves in bunches or platoons from one signal to another, arriving at the second signal before it turns green. This type of operation is desirable for two reasons: in the first place, it is well established that an intersection will handle more traffic if the traffic arrives and passes through the intersection without stopping, thereby eliminating the dead time required to get a stream of traffic moving; and second, the drivers find such a system more desirable because the necessity of stopping is eliminated.[25]

The automatic flow control of traffic system operates on the principle of introducing gaps in the flow of traffic so as to maintain traffic speeds above the level where shock waves are generated.

Shock wave generation. Experiments have shown that the accordian-like action which is characteristic of congested traffic flow is caused by periodic shock waves.[26]

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[24]Robert S. Foote, _Development of an Automatic Traffic Flow Monitor and Control System_ (New York: The Port of New York Authority, 1961).

[25]D. L. Gerlough, _Notes on the Use of the Digital Computer for Traffic Signal Control_, n.d., pp. 1-2.

[26]Robert S. Foote, Kenneth W. Crowley and Alan T. Gonseth, _Development of Traffic Surveillance Systems at the Port of New York Authority_ (New York: The Port of New York Authority, 1962), p. 2.

The shock waves are periodic reductions in the flow and speed of traffic. They are caused by the inability of that section in the roadway which has the least capacity to handle all of the traffic flow. Shock waves start at the point of lower capacity and move back through the traffic stream. They cause the vehicles to slow down or stop as they approach the low capacity points. Research into the problem of shock waves led to two main findings: that shock waves occur spontaneously under certain conditions; and that shock waves are a cause of congestion as well as an effect.[27] By maintaining surveillance on the traffic stream to determine when and where shock waves are to be generated, and taking action to prevent or absorb them, it is possible to minimize the loss in capacity due to the shock wave.

The purpose of inserting gaps in the traffic stream and speeds higher than those usually found in congested traffic is to increase traffic production. The momentary interruption of traffic entering a roadway does not delay approaching motorists. Since production on the roadway ahead is at a higher level, all motorists' trips are expedited by these gaps. This effect was demonstrated whereby congestion was reduced by one-third when gaps were inserted.[28]

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[27] Ibid., p. 3.

[28] Robert S. Foote, Kenneth W. Crowley and Alan T. Gonseth, Instrumentation for Improved Traffic Flow (New York: The Port of New York Authority, 1960), p. 15.

A problem that arises in initiating a system of gap insertion in traffic flow is that of public acceptance. Since the operation requires a periodic interruption of traffic entering the roadway for no apparent reason, it is necessary that the motorist be assured of a smooth and rapid trip so that one of the benefits of the system will be apparent to him. This is not the main benefit of the system. The main purpose is to gain greater traffic productivity through the critical roadway and thereby reduce the overall extent of congestion and delay.[29] By maintaining higher production along the roadway an overall reduction in delay to motorists on the roadway is experienced. In line with the need of public acceptance, the size and timing of the gaps must be carefully determined. With excessive gaps, speeds will be maintained but overall production will decrease.

The insertion of gaps tends to create a vehicle platoon system of traffic flow. Studies have indicated that, if signalized intersections are not spaced too far apart, platoons of vehicles tend to maintain a constant time-distance relationship. This, however, is subject to change. When a free-flowing platoon encounters a red signal and enters a stationary state, vehicles are compressed, filling

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[29]Robert S. Foote, Kenneth W. Crowley and Alan T. Gonseth, Development of Traffic Surveillance Systems at the Port of New York Authority (New York: The Port of New York Authority, 1962), pp. 5-6.

the intersection approach. When the signal changes to green and the free-flowing state is re-entered, the controlled movement results in an increase in distance from the front to the back of the platoon, thus decreasing the number of vehicles which can pass through the intersection.[30]

To understand how the behavior of platoons affect traffic flow, it is necessary to understand two processes which occur in vehicle traffic flow. One process is the decrease in speeds of successive vehicles in platoons. This decrease is caused by the fact that, since the vehicles are in platoons and therefore driving relatively close to each other, the fluctuations of speeds from one vehicle to the next will usually be such as to result in lower speeds. Fluctuations which would speed up successive vehicles are not likely nor desirable since the probability of having an increase in accidents is greater when vehicles follow too closely. The second process is that the traffic flow is highest when speeds are in a particular optimum range.

When these two processes are combined, it is evident that, as a vehicle platoon becomes longer, due to increasing traffic demand, and the speeds of successive vehicles become slower, the traffic flow will tend to fall below

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[30]D. L. Gerlough, _Notes on the Use of the Digital Computer for Traffic Signal Control_, n.d., pp. 1-2.

its capacity. This can be avoided by introducing gaps to prevent these long platoons from developing.[31]

To provide a base from which to operate the gap insertion system and to avoid excessive gap delays, the automatic flow control system is based on a one minute re-cycling basis, during which the system monitors both speed and volume and establishes automatically an input rate for traffic flow for one minute based on traffic conditions during the preceding minute. In operation, the computer classifies speed conditions at the point of congestion and infers density indirectly by measuring speeds upstream from the point of congestion to determine when shock waves begin to propagate. The computer controls the density by counting the number of vehicles passing through the point of congestion in one minute, and setting the number of vehicles to enter the roadway in the following minute higher or lower than the point of congestion flow depending on whether more or less vehicle delay is required. If speeds at the point of congestion are slow, fewer vehicles are allowed to enter the roadway than passed through the congested area in the minute before, and density thereby is lowered. This continues until the lower density results in raising speeds at the point of congestion.[32] The system is dependent upon

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[31] Foote, Crowley and Gonseth, _op. cit._, pp. 15-17.

[32] _Ibid._, pp. 5-9.

a continuous measure of the actual number of vehicles on a section of the road. When the vehicle density approaches a critical level, then the system must have the capability of exactly measuring the speed of each vehicle at points where shock waves might generate. As long as speeds are maintained, densities can be allowed to increase and a high flow rate will be realized. As soon as a trend of decreasing speeds becomes evident, gaps should be inserted until speeds are restored. As can be realized, this system requires numerous speed measuring devices as well as devices to measure actual density.

System operation. In operation, the first step is the surveillance of the roadway. This can be accomplished by means of closed circuit television, police traffic control personnel and vehicle detectors. The effectiveness of the surveillance system is determined by how rapidly it detects abnormal traffic situations.

Although the use of closed circuit television and police traffic control personnel have a definite value in the surveillance system, it was determined that the least accurate part of the system was the human observer. Attempting to exercise continuous control of traffic flow for long periods of time is extremely demanding on the individual. The observer must regularly evaluate information being received from several sources as well as consider the probable effects of his decisions on the traffic flow. In view of the frequency and rapidity with which the traffic flow changes, it is not possible for a man to provide the frequent traffic alterations required to maintain an efficient traffic flow. Added to the inability of man to maintain the high state of efficiency and accuracy required, is the relatively high cost of providing sufficient personnel on a daily basis.[33] The least expensive and most efficient method of surveillance is by use of vehicle detectors which have the capability of measuring individual vehicle speeds at frequent intervals. This is based on the theory that a drop in speed will provide the earliest indication of actual or potential congestion and delay on the roadway. The speed information is then furnished to the traffic flow control computer which automatically determines when gaps should be inserted in the traffic stream. The surveillance system will provide an automatic alarm to indicate when and where speeds have dropped below a critical pre-set level.

The flow computer scans the detector units and considers the number of vehicles which have passed the point of congestion in the preceding minute and then, by next considering the speeds of traffic approaching and at the point of congestion, establishes a maximum number of vehicles which may enter the roadway in the next minute. It should

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[33]Robert S. Foote, Development of an Automatic Traffic Flow Monitor and Control System (New York: The Port of New York Authority, 1961), p. 23.

be noted that although the system is programmed on a one minute re-cycling basis, any time suitable for local conditions may be substituted. After deciding each minute the number of vehicles which should enter the roadway in the next minute, the computer automatically adjusts a traffic spacer. By means of ultrasonic or induction loop vehicle detectors placed near the intersection or potential congestion point, the traffic spacer will count the number of vehicles entering the intersection or congestion point. When the amount which has entered in less than a minute is equal to the amount predetermined by the flow computer, the traffic spacer will automatically change the signal light to red for the remainder of that minute. The minimum stop time is seven seconds, which insures that resulting gaps in the traffic flow would be at least that long in duration. If the gap time was less than this, then there would be a tendency for vehicles to speed up and close the gap resulting in an increased size of the platoon and decreased overall road production.[34]

Detection system. Sensing traffic behavior is the critical point of any traffic control system. The automatic flow control system employs radar, ultrasonic and induction loop detectors. The radar speed sensor detector transmits tone pulses to the monitoring equipment

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[34] Ibid., pp. 23-25.

which measures the traffic flow, speed and density. The induction loop detector provides a similar level of detection performance at an equal cost. The ultrasonic detector was determined to be the most accurate and the least expensive.[35]

Most traffic signal systems have included a minimum amount of sensing capability. The sensing that has been used is generally volume counting. More adequate sensing of traffic behavior will improve traffic control systems. As an example, consider the situation when a vehicle platoon is moving in a progressive system in which the signal is timed to turn green as the platoon reaches the intersection. From time to time, there may be a queue of vehicles at the intersection. When such a queue exists, the platoon is required to slow down or stop. The number of vehicles which can clear an intersection from a standing start is much less than the number which can move through without being required to stop. By using a combination of presence detectors to sense the presence of a queue and speed or volume detectors located well back from the intersection to sense the arrival of the approaching platoon, it will be possible to give an early green signal to clear the intersection before the arrival of the platoon.[36]

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[35] Ibid., p. 8.

[36] D. L. Gerlough, Notes on the Use of the Digital Computer for Traffic Signal Control, n.d., pp. 1-2.

The detection system has the capability of providing data to the computer so that a prediction of the platoon arrival time is made. The ultrasonic detectors are placed well back from the intersection. The computer examines passage inputs until a substantial gap occurs; then it looks for a group of vehicles following the gap. When such a gap occurs, the time at which the first car of the group passed the detector and the speed of traffic are used to predict the time at which the first car of the next platoon will arrive at the intersection.[37]

When side street traffic is allowed to cross or enter the main street, minimum disruption to the main street traffic will occur if the arrival gaps in the main street traffic can be predicted and the signal timing changed accordingly. Gaps can be sensed by the detectors which are set back from the intersection. When the speed of traffic as well as the time at which the gap front passes the detector are known, the arrival of the gap at the intersection can be predicted and the signals changed to permit side street traffic to move in the intervening period.

__Reaction time__. The automatic flow control of traffic system is a relatively slow reacting system. Although the computer scans all detectors and processes a program in less than a second, it cycles itself on a one

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[37]__Ibid__., p. 8.

minute basis. Thus it normally uses a fifty-three second period to evaluate traffic conditions and trends in the cycle period. Once the computer recognizes a potential congestion point, it reacts instantaneously to the situation. In this system the speed of reaction is not as important as the ability to determine accurately the number of vehicles in the system and the individual speed of each vehicle.[38] It has the capacity of scanning all detectors in the system in less time than the "on or off" state of any single detector which is in the range of five milliseconds.

Fail-safe operation. The stoppage computer is the heart of the automatic detection system. In operation, the computer does two jobs simultaneously. First, by remembering the number of pulses it has received in the past few minutes, the computer establishes a flow rate. Secondly, the computer measures the time that has elapsed since the preceding vehicle has passed the detector. When flow is heavy past the detector a large number of pulses will be received in a few minutes. Then the computer will recognize that the passage of a relatively small amount of time without a vehicle passing the detector might be cause for alarm. When traffic flow is light and few pulses are received the computer would not generate an alarm until

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[38]Foote, Crowley and Gonseth, *op. cit.*, p. 14.

a much longer period passes with no vehicles passing the detector. Thus the system is fail-safe, because unless the system continues to operate and vehicles pass the detector an alarm is generated.[39] The alarm can be to the central control station for evaluation and action or to the local intersection controller where it can automatically revert to the existing signal system.

Limited experimentation with this system realized a 5% increase in traffic production plus several collateral improvements in traffic operations when shock waves were prevented.[40] This modest increase had a sharp effect on the degree and length of congestion and delay on the roadway, reducing it by 30%.

The discussion of the system indicated that the detection, evaluation and control of abnormal situations was best handled through automation, since man lacked the ability to perform the multiple functions required on a continuous basis without tiring and making errors in control and judgment. Further experimentation with this system indicated that at certain points in the system human control was necessary. These locations are the sections where traffic enters the system roadway. The traffic signals which were activated by the traffic spacer and flow computer were

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[39]Foote, _op_. _cit_., pp. 9-10.

[40]Foote, Crowley and Gonseth, _op_. _cit_., p. 4.

not effective in spacing the traffic flow. The length of time that traffic was required to stop to form the gaps usually ranged about ten seconds and since there was no apparent danger motorists were usually quite slow in stopping. The presence of a police officer at these critical points was effective in producing the required stops and providing effective spacing.[41]

Evaluation of the system. This system provides a means of increasing road traffic production and appreciably reducing traffic delay and congestion. But the locations where this system would be beneficial are limited. The nature of the system which involves eliminating shock waves, increasing production and reducing delay by means of inserting gaps in the traffic flow limits its application to roadway approaches to tunnels, bridges and sections requiring a change of phase to a lesser number of lanes. For these traffic situations, the system is good, but to attempt to employ it in conjunction with a traffic area pattern would necessitate a very large outlay in terms of the number of detector units, stoppage computers, traffic spacers and flow computers. To install a master computer large enough and with sufficient sophistication to monitor and direct the local flow computers would involve a cost

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[41]Robert S. Foote, Kenneth W. Crowley and Alan T. Gonseth, Instrumentation for Improved Traffic Flow (New York: The Port of New York Authority, 1960), p. 23.

far out of proportion to the job to be performed.

Centralized traffic signal control by a general purpose computer.[42] This system is an experimental pilot study conducted in the city of Toronto, Canada. In metropolitan Toronto, as in most large and growing urban areas, the existing traffic signal control system is inadequate. Local traffic engineers concluded that a modernized traffic signal using the latest in available equipment would still not be able to cope with existing traffic situations. Available equipment was not sufficiently flexible to meet changing conditions.[43]

In view of this, serious consideration was given to the possibility of evolving a new concept of traffic control which would have unlimited flexibility in the manner in which the traffic signals could be made to respond to traffic situations. From this study developed the pilot program of controlling traffic with a general purpose computer.

System operation. The computer is the heart of the automatic system. A standard business type digital computer which uses a magnetic drum and magnetic tape units for storage of numbers and instructions is employed. Input/

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[42] Sam Cass and L. Casciato, Centralized Traffic Signal Control by a General Purpose Computer (Washington, D.C.: 1960 Proceedings, Institute of Traffic Engineers).

[43] Ibid., p. 203.

output is normally accomplished by means of punched cards. However, during periods of traffic control, information is passed directly to and from the control panel of the electronic computer by means of a modified control board which receives the pulses from the detectors and transmits impulses to actuate the signal controls (see Figure 4).[44]

In taking over and maintaining control of the signals, the computer is guided by a master control program. The master control program contains several sub-routines which enable the computer to control any or all of the signals according to a specific signal control plan. These may be fixed-time, semi-actuated, full-actuated, volume density, or progressive type control systems.

For each intersection there is stored within the computer a table of constants or parameters which essentially describe the individual intersection. This table specifies the number of lanes on each approach, the distance of the detector from the cross walk, the minimum time which should be allowed for the green signal and the maximum time for a green signal which can be tolerated in any direction. When the computer actuates an intersection according to a certain control plan, it specializes the control to suit the data recorded in the parameter table. It is the control plan which enables the computer to keep track of the

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[44] Ibid., p. 206.

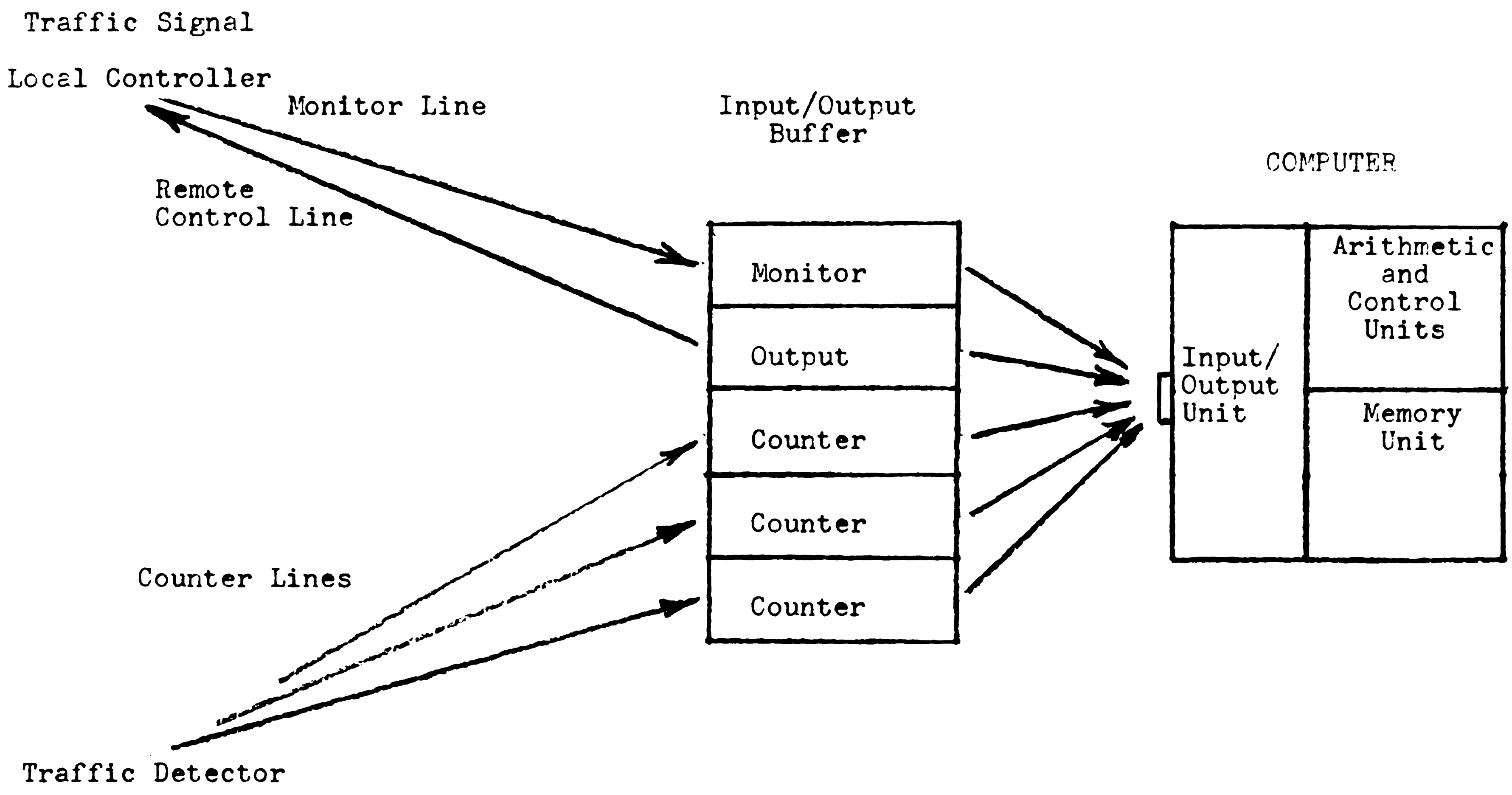

FIGURE 4

COMPONENTS OF THE AUTOMATIC SIGNAL CONTROL SYSTEM type actuation that is to be applied to each intersection. The computer has the capability of changing from one control plan to another, depending on the overall trend of traffic.[45]

When the computer is not controlling traffic, the input/output unit monitors the signals and registers the traffic counts, but the signals are actuated by the individual local controllers. In operation the computer reads the information from the input/output unit. As each signal advances into main street green the computer sends out a pulse which sets the modification circuit in the local controller to "remote" actuation. From this point on no change of traffic signal will occur at any intersection until the computer sends the appropriate pulse. In the event the computer should fail, the control reverts automatically to the local controller, thus providing a fail-safe operation.[46]

The computer receives inputs from system detectors via a central communication system. The traffic data are accepted by input counters which tally vehicle counts without reference to the main arithmetic unit of the computer. These counters can, however, be read by the arithmetic unit at will. By means of the arithmetic program provided to

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[45] Ibid., p. 209.

[46] D. L. Gerlough, Notes on the Use of the Digital Computer for Traffic Signal Control, n.d., p. 4.

it, the computer determines the cycle lengths, splits and offsets of each intersection. The computer sends commands via the central communication terminal to the individual intersection telling them when to shift from one green phase to the next.

Local controllers and system detectors are grouped by the computer into "systems" for purposes of control. This division is based on the relationship of the various intersections to the traffic being sensed. It is possible for one or more intersections to be shifted from one system to another by the computer program as traffic conditions change.[47]

Every two seconds the computer reads in all traffic counters, all signal monitors and the time. Computations are then carried out for each intersection in turn according to the control plan. Then an output cycle follows to permit appropriate signal actuations to be carried out and then the read in cycle is repeated. The monitors are checked to see that any actuations just carried out produced the required results. While the computer is repeatedly going through the read, compute and actuate cycle, a complete record of all the data is made on magnetic tape for future analysis.

Special programs. This system, in addition

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[47]Cass and Casciato, op. cit., pp. 208-211.

to the routine traffic control programs, has the capability of accepting special routines and putting them into effect on a need basis. It is feasible to let the computer decide when any special programs should be employed based on certain data established by the traffic engineer. For example, this system can have several programs to handle unusual weather conditions. It is possible to have a rain gauge tied into the computer in such a manner that the computer can initiate an appropriate program when a given rainfall level has been reached. The handling of unusual traffic patterns, such as occur in the vicinity of athletic events, can be an important task for the digital computer. On the day of the event, the time of the start of the event can be supplied to the computer. The computer based on stored information of past experience can set up the appropriate time the optimum program for handling regular traffic in addition to the traffic going to the event should be put into effect. As soon after the start of the event as the attendance figures are known, this information can be supplied to the computer for use in establishing the appropriate dispersal program. Progress of the game can also be fed to the computer so that it can estimate closing time and be prepared to handle normal traffic and traffic from the athletic event in an optimum manner.

Eventually it will be possible to program the digital computer to have learning ability and to evaluate experience.[48] In this manner it would be possible to determine if a particular program was especially effective in handling some special situation. If it were, information concerning the program could be stored for future reference, should a similar situation develop in the future. The handling of traffic around localized disasters such as fires and explosions would be an important utilization of this function.

Detection system. This system employed pole mounted, overhead radar detectors located on each approach to the various intersections. Detectors on the main street count traffic in two lanes. The detectors were mounted at distances from the intersection ranging from three hundred to six hundred feet, depending on the local traffic conditions.[49] A separate telephone circuit is used to connect each detector to the remote control area. At the computer location, all of the telephone circuits which connect to the various local controllers and traffic detectors are brought together at a single terminal board. A special input/output unit connected to the terminal board serves two purposes. It provides a visible display of the signal changes at each intersection, and the cumulative vehicle

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[48] D. I. Gerlough, Notes on the Use of the Digital Computer for Traffic Signal Control, n.d., p. 5.

[49] Cass and Casciato, op. cit., p. 206.

count produced by each vehicle counter and detector. More essential, it provides the coupling which allows the computer to read in the vehicle counts and monitored signals and to transmit the pulses which actuate the signals.

System results. The initial results obtained from the pilot study of this system indicated that delays during the evening rush hour period decreased 11% on the average and the morning rush hour delays were decreased 25% on the average. To the driver this meant that average speeds were increased from less than twelve or thirteen miles per hour to over sixteen miles per hour and traffic volumes were increased up to 20%[50]

In addition to the above, this system provides the following advantages:

1. It provides the greatest flexibility. All elements of signalization, cycle, length, split, method of coordination, sensitivity of response to individual detectors and to groups of detectors are completely adjustable by the computer. Operational changes to even the best special purpose signal equipment involve manual adjustments at the controller and possible changes in wiring or equipment. Such systems are capable of at least a fairly limited

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[50]Sam Cass and L. Casciato, "Toronto Successfully Pioneers Automated Control of Traffic Signals by General Purpose Electronic Computers," Traffic Engineering and Control, Vol. 4, No. 3, July, 1962, pp. 90-91.

number of simple changes. With the computer control, fundamental reorganization of the system can be brought about as often as desired with no alterations to the equipment.

2. Full use is made of existing fixed time controllers which provide stand-by service during periods of emergency or when the computer is used for other purposes.

3. The computer can be used for other than direct on-line control. It provides not only a very flexible way of controlling traffic, but also an analytical tool for evaluating the control techniques that are used for studying traffic trends, and for developing new control concepts that can improve the traffic control system.

Evaluation of the system. Since this system has been operated only as a pilot study, it is too early to make any definite statements as to its actual capability. The limited testing indicates that it will improve the existing traffic control signal system and reduce vehicle delays.[51]

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[51] Information obtained from personal correspondence with Mr. L. Casciato, Chief Engineer, Traffic Research Corporation, Limited, Toronto, Ontario, Canada, March 25, 1963.

CHAPTER IV

COMPARISON OF SELECTED FACTORS

This chapter presents a comparison of selected factors of the computer controlled traffic control systems. It will include a discussion, analysis and comparison of the following: (1) detection devices employed to provide the system input data; (2) the methods of processing the input/output data; (3) the control measures activated by the systems; (4) reaction time; and (5) the degree of human control required.

I. DETECTION DEVICES

The collection and processing of traffic flow data to assist in determining the cycle lengths, splits and offsets of the traffic control system is probably the most difficult part of developing a traffic control system. The methods of collecting and processing of traffic flow data have shown a steady advance in both technique and accuracy. The first generation of vehicle detection was performed by manual counts and leisurely studies. These were time consuming and relatively inaccurate. The results when employed indicated what was occurring at the time of the study and not what was happening at the instant time.

The second generation of vehicle detection methods saw a movement away from the use of humans for the detection and counting of vehicles. The use of crude, but reasonably effective, mechanical devices to record vehicle passage were next in the progressive improvement of detection devices. These included pneumatic rubber tube counters, electric counters and printing recorders. These devices measured vehicle passage and thus provided an accurate count of vehicles using the roadway in a given time period. They were limited to volume counts.

The earliest speed measuring devices were the speedmeters and placement detectors. The speedmeter is the simplest and least expensive of these systems. It was manually operated and required only a stop watch, an Enoscope and a measured distance of roadway. The enoscopes were normally placed 176 feet apart and the observer noted the time a vehicle entered the range of one scope and the time it passed the second scope. This time was recorded and the resultant speed was calculated. The basic construction of this system limited it to single lane movement and light traffic conditions.[1] A modification of this system using paired detectors and road tubes provided it with the capability of checking multi-lane roadways, but the short lived nature of the road tubes limited its usefulness to traffic research

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[1]Evans, op. cit., p. 153.

and law enforcement purposes.

The placement detector utilized a segmented contact strip which determined the location of a vehicle's wheels in respect to a lane reference line. This system, when used in conjunction with speed and volume counters, is useful in determining lane occupancy. The size of the strips and the fact that they could not be used for continuous and instantaneous collection of vehicle placement data limited their use.[2] Recent advances in the development of detection devices include radar, ultrasonic, infra-red, induction loop and electro-magnetic type detectors.

A detector device seldom used because of its complexity is the employment of photographic means to record speed, placement and vehicle classification. Its use is limited to special detailed traffic studies.[3]

In comparing the various detection devices employed in computer controlled systems it is necessary to know the basic operating principles and the limitations of the detection unit. The primary classification of vehicle detectors is presence or non-presence detectors. Presence detectors are those which will detect vehicles at all speeds including vehicles that are stopped. Non-presence detectors

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[2]Richard C. Hopkins, Vehicle Detection for Traffic Analysis and Control, Traffic Engineering, Vol. 31, No. 10, (July, 1961), p. 14.

[3]Ibid.

are those which will not detect vehicles travelling at speeds less than two miles an hour.[4] Further classification is made according to the functions required of the detector. For computer traffic control systems this includes vehicle detectors that will measure speed, count vehicle number and presence, classify vehicles by type, detect and measure lane occupancy, and lane density.

1. Pneumatic detector. This consists of a flexible tube placed at right angles to the path of travel. One end of the tube is sealed and the other is attached to a pressure actuated switch. When a vehicle passes over the detector it displaces a volume of air, creating a detectable pressure. Its accuracy is high for road capacities of less than 3,000 vehicles per hour per two or more lanes. It has the advantages of low cost and ease of installation and maintenance. It has the disadvantages of being vulnerable to traffic hazards, such as tire chains, dragged objects, sweepers, snowplows, skidding vehicles and theft. Snow and ice impair its accuracy. It is limited to the detection of vehicle passage.[5]

2. Electrical contact (permanent). This device consists of an impulse or positive contact treadle which consists of a steel base plate with a rubber pad

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[4]See Chapter III, pages 50-51, for detailed discussion.

[5]Evans, *op. cit.*, p. 154.

holding a strip of spring steel. The gap is filled with a dry, inert gas. Pressure of a passing vehicle causes a positive electrical contact for each axle. It can be attached to an electrical or electronic counter. It has the advantages of providing a separate count of vehicles for each lane and is not vulnerable to normal traffic hazards. It has the disadvantages of limited accuracy in high vehicle volume areas, inaccurate counts due to each axle being recorded without distinguishing between automobiles and trucks, rapid deterioration of rubber pad by heavy traffic and increased pavement maintenance costs. It is limited to detecting vehicle passage.[6]

3. Electrical contact (temporary). This device is similar in operation to the permanent electrical contact detector. It consists of a metallic in a rubber mould. It can be installed at any location. It has the advantages of rapid installation and removal and a long operational life. Its main disadvantage is that its efficiency drops in wet weather. It is limited to detecting vehicle passage.[7]

4. Photo-electric detector. This device consists of a light source and a photo-electric cell. The light source must be of sufficient intensity to cover the required lane distance. The photo cell must be housed and

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[6] *Ibid*. [7] Hopkins, *op*. *cit*., p. 15.

shielded from ambient light sources. Its accuracy is limited to single lane detection and areas of vehicle volume of less than 1,000 vehicles per hour. It has the advantages of simplicity, reliable operation, ease of adjustment and low maintenance requirements. It has the disadvantages of being limited to single lane roads and its lack of accuracy. It has a tendency to overcount traffic. It is limited to detecting vehicle presence.[8]

5. Radar detector. This device employs the doppler effect in which a radio signal or pulsed tone is transmitted and when it strikes a moving object it is reflected from the object at a different frequency from the incident signal. The reflected signal is received and the speed calculated. The range of the detector is limited by the power of the transmitter and the sensitivity of the receiver. It covers an elliptical pattern on the roadway. The radar unit is installed as a self-contained unit with the target vehicle serving as the signal reflector. The unit is normally mounted above the lane of travel. It has the advantages of not being subject to normal wear and low operating costs. It has the disadvantages of high initial cost, it requires elaborate supports, and maintenance must be performed by skilled personnel. The detector has a high degree of accuracy. It is limited to detecting vehicle

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[8]Evans, op. cit., p. 139.

passage and speed.[9]

6. Magnetometer. This device operates on a signal or impulse being generated when its magnetic field is disturbed by a passing metal object. It consists of a tightly wound coil installed below the pavement. It has the advantage of durability due to the lack of traffic wear. It has the disadvantages of requiring frequent adjustment, periods of instability, and a distortion effect and resultant inaccuracy if installed in areas with heavy electrical equipment or near underground storage tanks. It is limited to detecting vehicle passage and presence.[10]

7. Ultrasonic vehicle classification detector. This device operates on the principle of an ultrasonic wave generated by a vibrating diaphragm and focused into a narrow beam on the roadway. Any interruption of the sound wave is reflected back and the decreased distance or length of the wave closes a relay and records the object. The transceiver has two relays which are adjusted according to selected heights. This permits the unit to detect variable heights and thus classify vehicles by height. Pavement reflection of the sound wave is not recorded. The generator and pick up unit are mounted directly over the traffic lane. It has the advantages of using conventional radio tubes, and has low maintenance cost and ease of maintenance.

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[9] Ibid., p. 153. [10] Hopkins, op. cit., p. 16.

It has the capability of detecting vehicle passage, presence, lane occupancy, and vehicle classification.[11]

8. Ultrasonic doppler detector. This device operates on the same principle of transmitting an ultrasonic sound wave as the ultrasonic vehicle classification detector. It differs in that the sound wave is transmitted at a slight angle to the roadway and the receiver measures the doppler effect of the reflected wave. This device has the capability of detecting vehicle presence and speed.[12]

9. Ultrasonic presence detector. This device operates on the same principle as the detectors listed in paragraphs 7 and 8. It is a high resolution detector which senses the presence of vehicles under the sensing unit. It is limited to detecting vehicle passage and presence.[13]

10. Induction loop detector. This device consists of a loop of wire embedded in the surface of the pavement. It detects only metal objects passing over it. The passage of the metal object causes the inductance of the loop to be changed and recorded. This device has the advantage of durability and accuracy. It has the disadvantages

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[11] J. H. Auer, Jr., A System for the Collection and Processing of Traffic Flow Data by Machine Methods (A paper presented to the Freeway Operations Committee, Department of Traffic and Operations, Highway Research Board, Washington, D.C., January 8, 1962), p. 3.

[12] D. L. Gerlough, Notes on the Use of the Digital Computer for Traffic Signal Control, n.d., p. 12.

[13] Ibid.

of high installation costs and requires frequent adjustment. It is limited to detecting vehicle presence and passage.[14]

11. Infrared detector. This device consists of a photo-electric cell which is sensitive to infrared (heat) radiations. The heat source may be active or passive. The active infrared detector has the source of energy contained in the transceiver which is mounted directly over the traffic lane. The passive infrared detector has the source of energy mounted in the roadway and the receiver mounted over the roadway. This type detector has the advantages of being light in weight, fully transistorized and has a high degree of accuracy. It is limited to detecting vehicle presence and passage.[15]

A comparison chart illustrating the capabilities of the various vehicle detectors is shown in Figure 5.

Lane occupancy. Lane occupancy is a relatively new parameter obtainable through the use of vehicle presence type detectors as opposed to the conventional treadle or radar type detectors. The nature of lane occupancy and its relationship to vehicle density (vehicles per mile) is of major consequence to computer controlled systems, since a major factor in reducing traffic delays and congestion is to increase road production in terms of vehicle volume and speed.[16] If one were to draw a line down the

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[14]Hopkins, op. cit., p. 16. [15]Ibid., p. 13.

[16]Auer, op. cit., pp. 2-4.

TYPE DETECTOR	Condition Sensed Passage	Presence	Speed	Lane Occupancy	Classification
Pneumatic	X				
Electrical Contact (Permanent)	X				
Electrical Contact (Temporary)	X				
Photo-Electric	X				
Radar	X		X		
Magnetometer	X	X			
Ultra-Sonic Vehicle Classification	X	X		X	X
Ultra-Sonic Doppler	X		X		
Ultra-Sonic Presence	X	X			
Induction Loop	X	X			
Infra-Red	X	X			

FIGURE 5

COMPARISON OF VEHICLE DETECTORS

center of a traffic lane, the lane occupancy at any instant would be defined as the percentage of the line covered by vehicles. Vehicles packed bumper to bumper would produce a lane occupancy of 100%. Vehicles spaced at three vehicle lengths apart would produce a lane occupancy of 25%.

Although lane occupancy is quite similar in behavior to vehicle density, there are significant differences. Traffic consisting of a mixture of passenger cars and commercial type vehicles can create a wide variance in the relative degree of lane occupancy and density. If one mile of roadway contained 30 automobiles, the density would be 30 vehicles per mile and would have a lane occupancy of approximately 10%. If the same lane were occupied by 30 trucks, it would have a density of 30 vehicles per mile, but the lane occupancy would jump to approximately 20 to 30%, depending on the length of the trucks. It is obvious that, although the density rate is the same, the degree of lane occupancy or road congestion can differ. This differentiation is an important parameter for computer use. Since the computer would actuate traffic signals to increase road production based on the vehicle presence data transmitted by the vehicle detectors, the system would tend to over or under estimate the actual amount of road space available to receive traffic.

By experimentation it has been found that the degree of congestion in a traffic lane can be reliably ascertained by observing the degree of lane occupancy. The ultrasonic vehicle classification detector has the capability of distinguishing between vehicle height and length and thus providing the computer with the necessary data to compute accurately the actual road production.[17]

None of the computer controlled systems discussed in Chapter II employs the lane occupancy parameter as a function of the system. The primary reason is that at the time of the initial system development, the vehicle classification detector had not been developed to an operational stage.[18]

Inquiries directed to various cities throughout the country which are installing or planning to install computer controlled traffic systems indicated a wide variance in the type of detectors to be employed. Some reasons for the wide variance are cost of installation and maintenance, degree of accuracy and reliability required of the system, location of the detectors and the type traffic which predominates in the area. All agree that as the systems become operational and sufficient data are obtained to evaluate and modify the systems, that more sophistication and reliability in terms of detection ability, data processing and

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[17] Ibid., p. 3.

[18] D. L. Gerlough, Notes on the Use of a Digital Computer for Traffic Signal Control, n.d., p. 2.

control programs will be incorporated.[19]

II. METHODS OF PROCESSING INPUT DATA

The vast amount of traffic data generated by the vehicle detectors create a problem of tremendous scope. The information must be obtained from the detectors, reduced to a form by which it can be handled by the computer, processed and evaluated, compared with programmed data stored in the computer's memory unit, compared with data received in the previous time cycle, a decision made as to which traffic signal plan will provide the optimum traffic flow, and the decision reduced to the appropriate pulse commands to instruct the local intersection controller. All of these actions must be performed in times ranging from fractional parts of a second up to a few minutes. Obviously it is a task beyond the capability of man.

A typical method of processing traffic data from the time it is received from the vehicle detectors until it is transmitted to local intersection traffic controllers in the formed signal change instructions would follow this procedure. The computer scans the vehicle detectors and accepts the information that has been recorded in the cycle

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[19]Information obtained from personal correspondence with traffic engineers of the following cities: Chicago, Illinois; Detroit, Michigan; Lansing, Michigan; Los Angeles, California; New York City, New York; Seattle, Washington; and Toronto, Canada.

time. The detector pulses are automatically encoded and converted to a pulse tone format which can be accepted, read and stored by the computer. The information received may be in the form of vehicle speed, density, presence, passage, lane occupancy, vehicle classification, time of day or combinations of these.

The computer evaluates the input data in relation to programmed traffic parameters for each intersection and the traffic data received from previous cycles. Based on the programmed traffic control plans and existing conditions, the computer decides on the specific signal cycle, split and offset to be employed at each intersection. The computer then translates this decision into a series of pulsed tones to direct and actuate the individual traffic signals to follow the selected sequence and timing. The end result is the progression of traffic signal lights which direct and regulate the flow of traffic.[20]

During the normal sequence of events, the computer will periodically analyze inputs from system detectors determining whether there should be any change from the signal timing plan already in effect. When a change is to be made the computer will determine the new offsets and cycle updatings. The change may be made instantaneously or the computer may direct that a gradual transition to the new

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[20] Auer, <u>op</u>. <u>cit</u>., pp. 4-7.

cycle take place. The choice rests with the computer and would be based on developing traffic trends and how rapidly the change must be implemented to achieve the desired results.[21]

The computer real-time control of traffic and centralized traffic signal control by a general purpose computer systems operate on this complete centralized control method. All intersection traffic controllers are actuated by the computer based on a continuous flow of data from the detectors. The local controllers are completely dependent on the computer for actuation and any changes to the signal phase. The exception is when the computer fails or is disconnected. During these times the signals revert automatically to the existing signal system.[22]

The automatic flow control of traffic system is not quite so centralized. In operation the signal system is controlled by the stoppage computer and the traffic spacer. These two devices actuate the signals under normal traffic flow conditions. The flow control computer monitors all input data and maintains a cumulative total of the entire traffic picture. In the event of abnormal conditions, the flow computer, which has monitored and evaluated the traffic situation, will direct the traffic spacer to actuate

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[21]Gerlough, op. cit., pp. 3-4.

[22]See Chapter III, pages 52 and 73 for detailed discussion.

the required traffic signals to relieve the abnormal condition.[23]

III. CONTROL MEASURES ACTIVATED

The basic element of control activated by the computer system is the local intersection traffic control signals. Additional signals can be installed and activated by the computer to provide a more flexible and responsive system. This would include traffic directional arrows to indicate turning lanes, speed information signs to advise motorists of the optimum speed to travel, detour signs and arrows to reroute traffic automatically away from abnormal road conditions and route information signs to direct motorists to routes that will provide more rapid movement. The variations in this type of signals are limited only by the imagination and ability of the traffic engineer.

More important than the specific control device to be activated are the possible modes of control that can be initiated. The following modes of control are advanced by comparison with current, conventional traffic signal control systems, but they are feasible for implementation by a digital computer under the present state of development.[24] These modes are:

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[23]See Chapter III, pages 64-65, for detailed discussion.

[24]Gerlough, op. cit., p. 5.

1. Sophisticated cycle and offset selection.
2. Automatically adjusted progression.
3. Platoon arrival prediction.
4. Gap arrival prediction.
5. Combination of the above modes.

These control modes are programmed for the computer by means of a table look up procedure. Individual tables are provided for each combination of conditions. The entries in the tables are pre-determined settings of cycle, split and offset for each parameter combination. Local signals may be operated by a regulated fixed-time controller or by means of a semi-actuated controller with a regulated background cycle.[25]

The advantages of employing these various pre-programmed modes of control are that they are easily understood, provide traffic control programs for a variety of traffic situations, and the appropriate program is initiated automatically when fixed traffic input levels occur. The main disadvantage is that it requires a computer with a large memory storage unit to store the many pre-determined programs associated with the control plans to be activated.[26]

It is possible for the computer to provide every timing command to all of the local intersection controllers. When this is done the computer will deliver a pulse to the

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[25] *Ibid.*, pp. 6-7. [26] *Ibid.*, pp. 3-4.

intersection controller at the end of each green, amber, walk, wait, or other interval. With this high degree of control, the information levels on the communication transmission lines will be very high. This will also require that a large percentage of the computer's work cycle be spent in issuing commands to intersections. In the opposite direction, it is possible to put a high degree of intelligence in the local intersection controller and have the computer provide only supervisory information. This action increases the overall cost of the system, increases the maintenance problem and in some cases decreases the system's flexibility.[27]

The computer real-time control of traffic and centralized traffic signal control by a general purpose computer systems employ this highly centralized system of signal control. However, the number of control plans available are not as numerous or sophisticated as those mentioned. With the exception of the periods when the computer is disconnected or out of order, all signal changes are controlled directly by the computer. This provides for maximum system-wide coordination even though the type control plan utilized will vary from location to location and according to the traffic demand generated.[28] The automatic flow control

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[27] Ibid., p. 4.

[28] See Chapter III, pages 41 and 73, for detailed discussion.

of traffic system is less centralized and less flexible in the variety of control plans available. It operates on a selected re-cycling basis, during which gaps are inserted in the traffic stream by means of actuating the signal controllers. The length of the gap may vary depending on the instant traffic conditions, but the basic control plan remains the same. Under normal conditions the stoppage computer and traffic spacer actuate the signal lights while the flow computer monitors and supervises the system.[29]

The computer real-time control of traffic and centralized traffic signal control by a general purpose computer systems have a fail-safe operation whereby if there is a failure in the communication link or a failure in the computer power supply the system will revert automatically to a local intersection self-timing system.[30] The automatic flow control of traffic system has a fail-safe operation that transmits a warning signal from the stoppage computer to the flow computer if variations in the established vehicle flow rate are detected. This causes the flow computer to scan the entire system, locate the trouble location and take appropriate action. If there is a power or computer failure the system reverts automatically to the local signal controllers.[31]

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[29]See Chapter III, page 64, for detailed discussion.

[30]See Chapter III, pages 53 and 73, for detailed discussion.

[31]See Chapter III, page 67, for detailed discussion.

IV. REACTION TIME

The reaction time for computer controlled systems should be instantaneous, although extreme care must be exercised to prevent rapid fluctuations which have little effect on the total traffic flow picture from activating control plan changes. This is a major problem since it is often difficult to determine valid changes in peak flow as against momentary surges, since both will be reflected in the detection devices and in the master computer.[32]

The computer real-time control of traffic has the capability of scanning all the detectors in the system in less time than either the "on or off" state of any of the detectors. The computer has a scan rate of 25,000 detector scans per second. Since the minimum time interval for a detector change of state is five milliseconds, the computer has the capability of making 125 detector scans per 5 ms., which is within the required time limit. During this scan interval, the computer is also processing a control program for the system. The output data or pulses, while transmitted instantaneously, do not actuate the signals in the same interval. The computer estimates the exact time the signals should change and instructs the controllers accordingly.

[32] Information obtained from personal correspondence with Mr. K. E. Cottingham, District Traffic Engineer, Washington State Highway Commission, Department of Highways, Seattle, Washington, May 28, 1963.

The delay in actuating the signals may vary from a few seconds to several minutes depending on the traffic demand.[33]

The automatic flow control of traffic system is a relatively slow reacting system. Although it has the capability of scanning all system detectors in less than a second, it operates on a one minute re-cycling basis allowing a minimum time gap of seven seconds and a fifty-three second period in which to evaluate the traffic situation and react accordingly. In this system, speed of reaction is not as important as is the requirement for accuracy in determining individual vehicle and the exact number of vehicles in the system.[34]

The centralized traffic signal control of traffic by a general purpose computer system has the capability of scanning 1,000 detector points a second. During this period, the computer reads all input data, updates existing data and sequentially studies each intersection for possible revision to the control schedule in use. Although the computer has this capability, in operation it has been limited to performing these steps every two seconds. The overall coordinating program has a slower reaction time, ranging from a few seconds to several minutes, depending on immediate traffic conditions.[35]

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[33] See Chapter III, pages 51-53, for detailed discussion.

[34] See Chapter III, page 67, for detailed discussion.

[35] See Chapter III, pages 73-74, for detailed discussion.

V. DEGREE OF HUMAN CONTROL REQUIRED

In operation the computer controlled systems are to be completely a "hands-off" operation.[36] This statement must be examined in terms of personnel involved in the computer operation and those involved in traffic control functions.

The purpose of the computer controlled system is to increase road production and to reduce traffic delays and congestion. Whether this reduces the number of personnel used for traffic control functions is incidental.

The system operator will be primarily a supervisor to coordinate the activities of service and maintenance groups and the traffic control division of the police department. The traffic engineer must develop traffic programs for the computer. Although the computer analyzes and evaluates the traffic control plans in use, it is necessary for the traffic engineer to interpret the computer's analysis and prepare revised programs. Maintenance and repair of the equipment must be performed by skilled technicians. With the reliability of transmissions from the computer to local intersection controllers, via owned or leased lines, there is little reason for human intervention except for the routine maintenance required and occasional

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[36]Personal correspondence with Mr. L. Casciato, Chief Engineer, Traffic Research Corporation, Limited, Toronto, Canada, March 25, 1963.

verification of the computer programming results.[37] Thus for normal computer operations and maintenance there is a need for human control.

In developing a computer controlled system, provision should be made for human intervention and control at any stage in the systems operation. A system which could not be over-controlled by humans would result in an inflexible system. This would be especially true in those situations which might occur and which are not programmed into the systems routine and special programs. There should be provisions made for the control operator to intervene at his own discretion.[38] This may be nothing more than the relinquishing control of one intersection for special events or it may involve relinquishing control of an entire section of the system on a need basis.

A major point to be considered in installing a computer controlled system is whether it will permit a reduction in the police manpower requirements for traffic control. It is not anticipated that the implementation of computer controlled traffic systems will result in any substantial reduction in the number of police personnel assigned to traffic control duties. However, it will result in better

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[37]Personel correspondence with Mr. K. E. Cottingham, op. cit.

[38]Personal correspondence with Mr. S. S. Taylor, City Traffic Engineer, Los Angeles, California, June 4, 1963.

utilization of those assigned. This means that many of the police officers assigned to point control of traffic or manual operation of signal lights during peak traffic hours or emergency conditions would be released from these duties and assigned to more useful traffic functions.[39]

In the computer real-time control of traffic and centralized traffic signal control by a general purpose computer systems, human control is not required except for emergency actions. In the automatic flow control of traffic system police officers were required to assist in gaining compliance with the signals employed to form gaps in the traffic stream. Public education will in all probability correct this deficiency.

VI. COMPARISON OF SELECTED FACTORS

Figure 6 illustrates the similarities and differences, the strengths and weaknesses, and the degree of efficiency of the three computer controlled traffic systems.

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[39]Personal correspondence with Mr. L. Casciato, *op. cit.*

SYSTEMS	Computer Real Time Control of Traffic	Centralized Traffic Signal Control by a General Purpose Computer	Automatic Flow Control of Traffic
DETECTION DEVICES	Radar	Radar	Ultra-Sonic
PROCESSING INPUT/OUTPUT	Centralized control of all systems	Centralized control of all systems	Computer supervises system operation. Signal control decentralized.
CONTROL MEASURES ACTIVATED	All signal controllers. Variety of control plans.	All signal controllers. Variety of control plans.	All signal controllers. One basic control plan.
FAIL-SAFE OPERATION	System fails, control reverts to existing system.	System fails, control reverts to existing system.	System fails, control reverts to existing system.
REACTION TIME	25,000 scans/second. Continuous reaction.	1,000 scans/second. Performs cycle every 2 seconds.	Scans detectors every second. Operates on a 1 minute recycling basis.
HUMAN CONTROL REQUIRED	None.	None.	Limited.
EFFICIENCY	Provides 90% utilization of road capacity. 50% reduction in delay. (Simulation)	Provides 11 to 25% reduction in delay. 20% increase in traffic volume. (Actual)	Provides 5% increase in road production. 30% reduction in delay. (Actual)

FIGURE 6

COMPARISON OF SELECTED FACTORS

CHAPTER V

SUMMARY AND CONCLUSIONS

Traffic congestion is a relative thing which varies with the size of the city and the experience of the individual. It means more lost time in travelling from trip origin to destination, greater delays in movement of persons and goods, increased opportunity of being involved in a collision and increased consumer costs for services.

I. CURRENT TRAFFIC CONTROL SYSTEMS

__Traffic officer control__. The employment of police officers for traffic control functions varies from place to place. They may be used for point control of traffic, or patrolling roadways, or monitoring traffic flow from aircraft or by means of television cameras. Although the means vary, the desired results of their activities are the same: to keep traffic flowing smoothly and as quickly as is consistent with safety, and to prevent traffic delays and congestion. Working alone or in groups, their efforts are characterized by an inability to see beyond their immediate location, difficulty in communicating with other traffic control elements, difficulty in coordinating their efforts with other areas within the system, limited ability to predict when and where traffic congestion will occur, slow reaction time in recognizing and reducing abnormal traffic situations and a lack of knowledge of the effect that their efforts will have on the remainder of the traffic system. Their actions are essentially limited to correcting an existing abnormal situation rather than preventing the occurrence of the situation.

Traffic control signal operations. Traffic control signal operations are classified according to the alternating movements permitted, time apportionment and time relationships of adjacent controlled intersections. The simplest method of moving traffic should always be used.

Simultaneous system. This system employs a zero offset with all signals on the common street showing the same signal indication at the same time. The simultaneous stopping of all traffic on the common street prevents continuous movement and results in high speeds between stops, but low overall speed.

Alternate system. This system employs an offset which is one-half the cycle length. Adjacent signals show opposite indications to the common street at the same time. This system can provide continuous through movement under favorable conditions. Equal phase times are required for both main and side street traffic which is inefficient if traffic volume is higher on the main street. It is not adaptable to streets having blocks of unequal length and it reduces road capacity during peak hours of traffic.

Fixed time operation. In this system the signal indications are governed by a pre-determined program. The length of each signal interval and the time required for a complete cycle are the same for a given program. It is possible to pre-set additional timing programs for different times of the day. This system is relatively simple and can be quickly changed to allow for additional phases. It can be interconnected with other traffic areas for a coordinated systems operation without adding special equipment. Fixed time control does not allow for short time variations in traffic volume and thus creates traffic delays for main street traffic during low volume periods.

Simple progressive system. This system employs the same cycle length at all intersections, but the offset has no fixed relationship to the cycle length. A vehicle is able to enter the system and pass through every intersection without being stopped. The offset is dependent on the distance between adjacent intersections and the permissible vehicle speed. This system is normally suitable for use on one-way streets having a reasonably constant traffic volume and vehicle speeds.

Flexible progressive system. This system employs the same cycle length at all intersections, but the phase time can be varied in accordance with traffic requirements. The offset can be varied to allow for unequal spacing.

The entire system can be varied to meet different traffic requirements. This system must be of the interconnected type with a central master controller supervising all time relationships and coordinating all cycle changes. The system provides for the continuous movement of vehicle platoons with reduced delay and at an average pre-planned speed. High and low speeds are discouraged since both would be penalized by delays at subsequent intersections.

Traffic actuated system. This system is operated by traffic demand. The length of each signal interval and the overall cycle length are infinitely variable. Delays are held to a minimum at individual intersections, but since each signal unit acts independently of and without coordination with any other signal, it may cause delays and congestion at other locations in the system.

None of these systems, with the exception of the traffic actuated system, is responsive to immediate and changing traffic needs. Their cycle lengths, splits, offsets and timing are determined by what occurred in the past, not what is occurring at the instant time. They are inflexible in the sense that changes to the timing cycle require adjustment to the individual controllers or to the master controller. The time required to react to changes in the traffic situation reduces the system to the role of corrective rather than preventive action.

II. COMPUTER CONTROLLED TRAFFIC SYSTEMS

Computer real-time control of traffic. This system operates on the principle of control based on traffic demand. It is completely responsive to present traffic conditions and not on pre-set, fixed time operations based on data collected in the past. The traffic artery carrying the high volume traffic will control the signal right of way until such time as traffic demand from a side street necessitates a change of signal. The change duration will be decided by the computer in relation to the traffic volume of the main and side streets.

This system is not in operation. It is a traffic control system model developed through simulation of actual traffic conditions by means of an electronic computer. Simulation involves introducing data into a computer and testing various solutions to a problem. It involves the duplication of actual conditions in a computer. This simulation model employs as its central feature the concept of traffic in relation to movement and delay.

The control model employs a closed loop control system in which no outside action or control is required. The system receives its input data from detection devices, transmits the data to the computer, computes the appropriate traffic program and then activates the signal controllers. The system is predictive in the sense that it predicts traffic problems before they actually exist and takes the necessary control action to prevent their occurrence.

The system employs a radar type detector to detect vehicle passage and speed. The computer has the capability of scanning all detectors in the system in less time than is required for a change of "on or off" state of any individual detector. With a capability of performing 25,000 detector scans per second, the computer can effectively control 30 signalized intersections. At the same time it processes the necessary control programs to actuate and sequence the traffic signal controllers. The system has a fail-safe operation in that it reverts control automatically to the existing signal control system in the event of computer failure.

Estimated results of the simulated systems efficiency as projected from computer test results to an actual traffic process are a 90% utilization of road capacity as opposed to 40-60% capacity with existing systems and a 50% reduction in vehicle delay. In addition, it provides a valuable tool for predicting and evaluating future traffic control plans.

<u>Automatic flow control of traffic</u>. This system operates on the principle of inserting time gaps in the traffic flow to form vehicle platoons which will result in maintaining vehicle speeds above the level at which shock waves are generated. The elimination of shock waves in traffic

flow results in increased road production and decreased delay to the motorist.

Extensive reliance is placed on the accuracy of the detection system. Radar, induction loop and ultrasonic type detectors were tested. The ultrasonic detection unit was determined to be the most accurate in operation and the least expensive in overall cost. The vehicle detector transmits data pertaining to vehicle presence and speed to the traffic flow computer which determines when gaps should be inserted in the traffic flow and the duration of the gap. The information is transmitted to the traffic spacer which adjusts the signal light sequence in accordance with the instructions. Once a flow rate is established, the detectors, stoppage computer and traffic spacer operate independently, with the traffic flow computer serving to monitor the operation. In the event the traffic flow rate changes, the flow computer automatically scans the system and issues new instructions to the traffic spacer until the flow returns to the normal flow rate.

The system operates on a one minute re-cycling basis in which the minimum gap time is seven seconds, thus providing a fifty-three second period for the flow computer to analyze the traffic data and predict potential traffic problems. The traffic spacer is informed of what action to take and when to take it.

The fail-safe operation of the system is based on the operating principle that unless vehicles are being recorded by the vehicle detectors within reasonable limits of the established pulsed flow rate, the stoppage computer will alert the flow computer to evaluate the situation and take the necessary action to correct the situation. In the event of a computer failure, the control functions revert to the existing signal system.

Limited test of this system realized a 5% increase in traffic production and a 30% reduction in traffic delay and congestion. A limited degree of human control was necessary to insure compliance with the short stop intervals which were used to create the time gaps in the traffic flow. This system is somewhat limited in its application to urban traffic control systems. It is best suited for roadway approaches to bridges and tunnels and areas where traffic lanes are suddenly reduced in number. The present state of the system development limits its use for normal traffic patterns and areas because of the large number of detection devices required and the requirement for a large computer with a high degree of sophistication.

Centralized traffic signal control by a general purpose computer. This system employs a central master control computer which has complete control over every signal within the system. The computer is programmed with a master control program which contains several sub-routines which may be applied to any or all of the signal controllers within the system. The computer also contains a parameter table for each intersection which minutely describes the intersection. Based on traffic data transmitted by the vehicle detectors, the computer evaluates the information in respect to the parameters of the particular intersection and selects a signal control plan to move the traffic through the intersection. This action is also coordinated with the other signalized intersections. The system is responsive to all changes and demands of the instant traffic situation.

The system employs pole mounted detector units which are adequate for the present system. The computer has the capability of performing 1,000 detector scans per second and simultaneously processing the control plan to handle the traffic requirements being generated. Special programs and traffic situations can be programmed into the computer for future use. The computer will automatically select the correct program in accord with traffic demand.

In the event of a computer failure, the control function automatically reverts to the existing signal system.

The initial results of the pilot operation program indicated that traffic delays decreased by 25% during the morning peak hours and by 11% during the evening peak hours. This reduction of traffic delay resulted in an overall increased travel speed and a 20% increase in traffic production.

III. COMPARISON OF SELECTED FACTORS

Detection devices. The analysis of the various types of vehicle detectors available and in operation indicate that those with multi-sensing capabilities are more productive and practical for use with computer controlled systems. Radar, magnetometer, ultrasonic vehicle classification, ultrasonic doppler, ultrasonic presence, induction loop, and infrared type detectors possess these multi-sensing capabilities. Of these tests indicate that the radar, ultrasonic and induction loop are the most practical and accurate for traffic control use. This selection may vary according to the particular requirements of the system. The ultrasonic vehicle classification detector, when coupled or coordinated with a vehicle speed detector, offers the best accuracy and dependability for future systems.

Methods of processing input/output data. The major difference in the input data processing cycle is the type and degree of control exercised by the master controller over the systems operation. The sequence of action is receipt and transmission of traffic data to the computer, the analysis, comparison and computation of control programs by the computer, and the transmission of instructions to actuate the signal control devices.

In the computer real-time control of traffic and centralized traffic signal control by a general purpose computer system the input data are transmitted directly to the central computer where it is evaluated and compared with data stored from previous cycles. It is then compared against the parameter table for the particular intersection and with the traffic plan currently in effect. The computer determines if a change should be made and which traffic control plan should be implemented. This is a highly centralized processing system.

In the automatic flow control of traffic system, the computer continuously monitors the systems input. It continuously analyzes the total situation. The routine analysis, comparisons and reactions are made by the local stoppage computer and traffic spacer. The master flow computer only directs the system when abnormal conditions arise. This system is less centralized and less flexible than the other systems.

<u>Control measures actuated</u>. In all cases the systems actuate traffic signal control devices, which may be in the form of lights, arrows or sound alarms. The type device actuated is less important than the methods in which the devices operate.

The computer real-time control of traffic and centralized traffic signal control by a general purpose computer system employs a variety of traffic signal control plans which are placed in effect by the central computer. They are highly centralized systems with a maximum degree of responsiveness to traffic demand.

The automatic flow control system is less highly centralized, but it is equally responsive to changing conditions. It operates from one basic plan with an infinite number of variations.

Reaction time. The reaction time for the various systems differs according to the requirements of the system and the type computer employed.

The computer real-time control of traffic system employs a computer which has the capability of performing 25,000 detector scans per second. The scan of the detectors must be performed in less time than the "on or off" state of the detector to avoid miscounting the number of vehicles. The minimum "on or off" time is five milliseconds, which gives the computer the capability of scanning 125 detectors in the minimum time. The computer reacts instantaneously to traffic demands, although it will phase its reactions to have the optimum effect on the traffic flow.

The automatic flow control of traffic system operates on a one minute re-cycling basis. It scans all detectors in the system in less than a second, but times its reactions to correspond to the cycle time limits. The cycle time can be varied to meet existing traffic requirements.

The centralized traffic signal control by a general purpose computer system has the capability of performing 1,000 detector scans per second. The system is timed to scan all detectors every two seconds and prepare its traffic programs accordingly. Although slower than the real-time system, it is completely responsive to traffic demands.

Degree of human control required. The systems are designed to be a "hands off" operation. Each system requires human assistance and direction in preparing programmed data, installation and maintenance. The automatic flow control system requires police control to insure compliance with the momentary stop requirements for inserting the time gaps in the traffic flow.

It is not anticipated that the use of computer systems will reduce the number of personnel assigned to traffic control functions, but it will provide for better utilization of these personnel.

Conclusions. The employment of computer controlled traffic control systems will provide a more efficient and responsive control system. Limited operational use indicates that traffic delay can be reduced from 10 to 50%. The decrease in traffic delay and congestion will result in increased road production or number of vehicles able to travel a road system in a given time. This increased road production will range up to 90% of maximum capacity. These improvements in traffic flow patterns of urban areas will provide a substantial decrease in the overall economic cost of traffic congestion.

1. The computer real-time control of traffic system predicts the highest degree of improvements for urban

traffic control. It cannot be stated that this will occur, until such time as the system is applied to actual traffic conditions. Simulation models attempt to test the system against all known variables, but the actions of individual drivers cannot be predicted with a sufficient degree of certainty to enable traffic engineers to program them adequately in a simulation model.

2. The automatic flow control of traffic system performs its required function in relation to specific types of traffic situations. The limitations of the system preclude its use as a general traffic control system.

3. The centralized traffic signal control by a general purpose computer system has been in operation on a pilot model basis and has demonstrated its ability to improve the existing traffic control system. It is a flexible and responsive system which can be employed in any urban traffic situation.

4. The ultrasonic vehicle classification detector is the most advanced, accurate and versatile detector unit in operation. It will provide the detailed and discriminatory data required by a computer controlled system.

5. The use of computer controlled systems will not appreciably reduce the number of police officers required for traffic control functions. It will permit better utilization of personnel by relieving the police of the necessity of standing point control of traffic during peak traffic hours.

Recommendations. Since the use of computer controlled traffic control systems is relatively new, it is recommended that additional studies be made of the following areas:

1. The applicability of the General Motors Corporation's Traffic Pacer system to urban and freeway traffic.

2. The feasibility of linking urban arterial and freeway traffic systems under a coordinated computer controlled system.

3. The development of a completely automatic predictive traffic control system for the Congress Street Expressway, Chicago, Illinois.

4. Follow up study on the results of the computer controlled system currently undergoing tests in Toronto, Canada.

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