TRAFFIC CONTROL
AT
SIGNALIZED STREET INTERSECTIONS

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SYNOPSIS AND ACKNOWLEDGMENT

The term traffic, as usually employed in connection with street and highway traffic control, implies two elements, the vehicle and the pedestrian.

Although pedestrian movements were given some consideration in the intersection studies as developed in this dissertation, motor vehicles formed the principal objective in the analysis herein recorded.

In the first seven chapters which trace the development of present day methods, an attempt was made to present a composite picture of traffic control at signalized intersections. Chapters I and II, treating of traffic regulation and the traffic officer, although not pertaining directly to the subject in question, were deemed essential to forming a proper background to the more recent forms of control.

Beginning with the early forms of signal control, such as the original traffic towers, Chapters III and IV present in chronological order the various stages of development leading to the present form of signal almost universally adopted throughout the United States.

As a result of the tremendous development of the automotive industry, coordination of movement became a necessity. This phase of the problem forms the subject matter for Chapter V. The three systems, including the simultaneous, the alternate, and the flexible progressive, are discussed from a historical point of view, starting from the first crude attempts at coordination and culminating in the refined systems as presently operating in the larger cities of the country.

As timing forms the basis in the design of traffic control systems, this subject was treated at some length in Chapter VI, with emphasis having been placed on the graphical methods of analyzing this phase of the problem.

The latest advance in this field consists in the traffic-actuated signal. Chapter VII discusses this type of control giving the various forms of actuation, and explaining in detail the principle of the treadle-operated signal, the type almost universally used for such traffic-actuated installations.

In the past very little information has been available on the movement of left-turning vehicles at street intersections. Discussions relative to the timing of traffic control signals were based on the assumption that there were no left-turning vehicles present. With the view of obtaining factual data relative to this disturbing element in traffic flow at signalized intersections, the author conducted an investigation at four intersections; one in Ann Arbor, Michigan, and three in Detroit, Michigan.

Chapter VIII forms the report of this study, discussing the field work of observing actual traffic movements, and the office work comprising the compilation of data obtained from 9000 pictures, including 5000 vehicles, of which 500 were left-turning vehicles.

In the analysis of this material the following information was obtained:

(a) Average velocities of left-turning vehicles.

(b) Relationship found to exist between left-turn speeds and volume of traffic.

(c) Proportion of left-turning vehicles actually causing delay.

(d) Proportion of vehicles using inner and outer lanes, respectively.

(e) As a result of (d) the conclusion that the left-turning vehicle must be considered in determining the critical lane in the mathematical treatment of signal timing.

(f) Application of this data in the development of a delay factor used to rationalize two existing formulas for traffic signal timing.

In the preparation of this material the author wishes to acknowledge his indebtedness to Professor R. L. Morrison who supervised the work and whose many criticisms were most helpful; to Professor R. S. Swinton, who made many valuable suggestions relative to the investigation of left-turning vehicles; and to Lt. Herbert McCaske, Detroit Police Department, whose cooperation facilitated the field work carried on in Detroit.

CHAPTER I

THE EVOLUTION OF TRAFFIC REGULATION

One of the features comprised in City Planning as we understand it today, is the street system, the medium whereby the daily business is carried on and the people gain access to their homes and places of work, recreation and amusement. Such street systems once planned and laid out, are usually considered as permanent additions.

That this feature of suitable thoroughfares was a major consideration in early town planning in the various towns, can hardly be doubted; yet, whether the facility with which such streets should serve their purpose was of major importance with early town planners, is hardly probable. Congestion, as we understand the term today, was the exception, rather than the general rule.

The city planner of our time must include a study of the traffic problems of the town, not only providing for traffic in the working out of the street plan, but also for its regulation, in order that the existing street facilities may be used to their fullest capacity.

ROMAN REGULATION

Many early roads were constructed which served a rather large population and which led to some central point, either for commercial, political or social purposes. Such was the case for the ancient city of Rome. After Rome had become the central governmental seat for what was then the recently conquered Roman Empire, and the famous system of roads had formed a network over a great portion of this territory, with twenty-nine major thoroughfares radiating from it as the center of a system of highways totaling 50,000 miles, congesting in that city became a problem which demanded serious consideration.

In the reign of Julius Caesar an attempt was made to meet these traffic conditions by regulation, which required that all vehicles, with the exception of those belonging to public officials and citizens of high rank, were forbidden to enter the central areas of the city. With the Empire extending its boundaries, other seats of government were established, constituting centers from which the main highways started, and these experienced similar conditions of congestion, necessitating further legislation to eliminate the evil.

LONDON REGULATION

In 1285, Legislation was passed in England relating to roadside development, thus assuring public safety and public convenience. The General Turnpike Acts of 1822 and 1823 were rather comprehensive in treating with the rules of the road in England. The famous court ruling, "The King's Highway is not to be used as a stable yard," was invoked during the reign of Henry the Eighth, and later restated by Lord Chief Justice Ellenborough in 1812, when a certain Cross was found guilty of permitting a Greenwich stage-coach to remain for three-quarters of an hour twice a day in the street near Charing Cross Station " to the annoyance of the King's subjects." This same ruling is still recognized in the American courts of today.

With the appearance of steam as a motive power in the early part of the nineteenth century, we find the self-propelled vehicles taking their place on the streets and highways. This form of transportation was soon to be made the object of restricting legislation, brought about to a great extent by the stage coach operators who feared this new form of competition, and by the farmers who foresaw a decline in the price of their horses. In 1836, Parliament imposed a tax on these self-propelled vehicles, and required a man to precede each vehicle with a red flag to warn pedestrians of its approach. In 1861 the "Locomotive Act" was passed imposing the following restrictions:

> "The drivers of locomotives must give as much space as possible for the passing of other traffic.
>
> "Every locomotive must be instantly stopped by the person preceding the same, or any other person with a horse or carriage drawn by a horse, putting up his hand as a signal to require the locomotive to be stopped.
>
> "Any person in charge of a locomotive must provide two efficient lights to be affixed conspicuously, one at each side in front of the locomotive."

Almost every new idea which is destined to revolutionize some of the staid habits of mankind meets with such traditional opposition. Towards the beginning of the nineteenth century, when the self-propelled free-wheel vehicle began to appear on the public streets a decided skepticism soon evidenced itself, at times taking the form of persistent opposition. This opposition was prompted by two motives: The excessive speed of the vehicles which endangered the safety of other street users; and the competition which it presented to other forms of transportation.

London had been faced with a traffic problem in its various forms for more than a century. At one time the River Thames was the principal traffic artery of the city with several thousand "wherries" almost the sole means of transportation. About 1720, hackney coaches, cabs, and omnibuses entered into competition with the "wherries" and the merchants were greatly incensed over the changed travel habits of the public. They complained bitterly that their customers were finding it too convenient to travel to competing stores in other sections of the city, and they even succeeded in securing convictions of omnibus drivers as they technically "loitered" while picking up and discharging passengers.

The London Metropolitan Streets Act of 1867 endeavored to control the unloading of vans, forbidding them to stand for longer time than is necessary to load and unload. This ruling tended to increase the difficulty rather than improve conditions. Another clause of this act forbade timber or other lengthy merchandise to be transported through certain streets.

Observations showed that every omnibus and cab that used the main streets of the City of London and its approaches was delayed an average of half an hour every day; and every van that passed through its narrow lanes was delayed at least an hour and a half. On May 4th, 1891, a count showed that 20,372 vehicles passed into the City. The delays of these vehicles was estimated to result in a loss of about 5,000 pounds a day, or 1,500,000 pounds a year.

The Royal Commission of London Traffic in its report of 1905 points out that the evils of vehicular to pedestrian traffic, and delay and congestion of the vehicular traffic inside London were becoming more and more acute. With an increase of population in sight it became urgent that the natural movement from crowded centers to the more open country be favored. It was felt that not only mitigation of the existing evils was needed, but also provision to meet the growing wants of the future and prevent a repetition of the mistakes that had been made in the past.

The Report calls attention to the delay and congestion to be found at intersections of cross streets. The Advisory Board of Engineers, in their report, prepared complete analyses and diagrams of the traffic at certain points and suggested specific works to relieve these unsatisfactory conditions.

Road widening at "junctions" and formation of "circuses" were strongly recommended and, when carried out, proved to afford relief of congestion at these points.

During this period (1907) there became evident a marked change in the substitution of motor for horse-drawn omnibuses, and this not without considerable dissatisfaction at certain of its accompanying features. Complaints had been directed at the dangerous speeds, the noise, the offensive droppings of grease, and the exhaust discharges of these vehicles, and the damage and discomfort caused by the vibration due to their passage, especially over narrow, rough and poorly maintained roads. Notwithstanding these frequent complaints, the local authorities failed to take any steps to reduce the speed limits in the crowded districts of the city.

EARLY HISTORY OF TRAFFIC REGULATION IN THE UNITED STATES

Legislation to guarantee public safety among the early settlers in our own country existed in Newport, Rhode Island as early as 1678, where, because of a street accident, the Assembly enacted a law against reckless driving. In 1757 the Board of Selectmen of Boston, Massachusetts, passed an ordinance limiting the speed of all vehicles to a maximum of an ordinary footpace.

The end of the nineteenth and the beginning of the twentieth century saw the advent of self-propelled free-wheel vehicles; and at the same time the problem of street traffic control was making its presence felt.

About the year 1902, the little steam stanleys were giving considerable trouble to the police, with the result that we find their drivers frequently being brought before the judge for violation of the existing speed limits of from seven to fifteen miles per hour. The motor vehicles were soon to be subjected to similar restrictions. The St. Paul Park Commissioners decided, June 30, 1904, that automobiles were forbidden to use River Drive between Summit and Marshall Avenues because of the fact that horses were frightened by their presence. The City Council of Chicago prescribed a limit of ten miles per hour and four miles per hour when approaching the intersections, - July 13, 1904. At this same time Atlanta, Georgia, had an ordinance prescribing a speed limit of eight miles per hour within the fire-limits, and fifteen miles per hour in all other parts of the city. Kansas City prescribed a limit of eight miles per hour; Pratt City, Alabama, made a misdemeanor of speed exceeding six miles per hour; Northfield, New Hampshire, had a six miles per hour limit, and required motorists to come to a stop when meeting a team, if the driver of the latter requested it; Pittsburgh used speed traps checked by bicyclists to maintain a speed of eight miles per hour.

From its first appearance on the highways the motor vehicle left the impression that here was an instrument of danger. This new anxiety had its first crude expression in attempt to hold the automobile down to somewhere near the speed of the horse, with the hope that it was expected to behave like a horse. The early lawmakers failed to comprehend that, notwithstanding laws to the contrary, a machine built to run forty and fifty miles an hour could not be held down to such unreasonable limitations as they were trying to enforce. They did not grasp the fact that the motor car had come as an inevitable step in the development of civilization, and that it was here to stay.

According to William Phelps Eno, the pioneer of the traffic control movement in the United States, regulation of street traffic was practically unknown in New York prior to the year 1900, as described in these words: "Although traffic was much less than now, blockades were frequent throughout the city. Many unnecessary hours and often the greater part of the day and night were consumed in transporting merchandise from point to point, especially in the downtown shipping districts. Charges were increased proportionately with the time consumed. Conditions were execrable so far as time, economy, comfort and safety were concerned, and the police, without systematic direction, were powerless and in fact practically at the mercy of the mob. Collisions between policemen and truckmen, cabmen and others were of common occurrence, and it was only by resort to the "night stick" that in many instances blockades could be cleared away."

During the first years of the present century Mr. Eno took a very active part in the traffic situation of New York, and with the aid of the public officials, particularly the Department of Police, succeeded in bringing about what might be termed the beginning of traffic control in that city.

Several articles published by Mr. Eno during the first decade of the twentieth century aided in bringing about a change of conditions in this regard. In 1900 there appeared "Reform in Our Street Traffic Most Urgently Needed," and "Suggestions for the Management of Carriages at Entertainments," and in 1901, "Rules of the Road Revised." The last named took the form of a series of street ordinances, and in 1903 was presented to the Board of Aldermen. But because of political reasons it met with serious opposition from this body. After examining the City Charter, the Penal Code and existing Ordinances, it was discovered to be within the legal jurisdiction of the Police Commissioner to act independently of the Board of Aldermen in the control of the street traffic of the city.

The printing of seventy thousand of Mr. Eno's ordinances in the form of a folder, "Rules for Driving" in 1903, might be termed the real beginning of systematic street traffic regulation in the City of New York and in the United States. Following this beginning, the first one hundred blue and white enamled signs directing that "Slow Moving Vehicles Keep Near Right Hand Curb," were erected on Fifth Avenue and Broadway.

The cities of Boston and Baltimore soon followed in the footsteps of New York in endeavoring to establish some form of control of traffic on their streets.

The toll exacted by the motor vehicle on our streets and highways in 1923 was 22,600 deaths, 678,000 serious personal injuries and $600,000,000 as an economic loss. As a result of this appalling situation, Herbert Hoover, as Secretary of Commerce, and acting in cooperation with interested groups and individuals throughout the country convoked the First National Conference on Street and Highway Safety in Washington, D. C. in 1924.

Since that time three other similar Conferences were held. The reports of these meetings are here listed.

FIRST NATIONAL CONFERENCE ON STREET AND HIGHWAY SAFETY--1924

I Statistics
II Traffic Control
III Construction and Engineering

IV City Planning and Zoning
V Insurance
VI Education
VII The Motor Vehicle
VIII Public Relations

SECOND CONFERENCE--1926

I Uniformity of Laws and Regulations
II Enforcement
III Causes of Accidents
IV Metropolitan Traffic Facilities
V Statistics
VI Public Relations

THIRD CONFERENCE---1930

I Protection of Railway Grade Crossings and Highway Intersections
II Maintenance of the Motor Vehicle
III Measures for the Relief of Congestion
IV Uniform Traffic Regulation
V Traffic Accident Statistics
VI Manual on Street Traffic Signs, Signals and Markings

(Report of the American Engineering Council)

FOURTH CONFERENCE--1934

I Uniform Motor Vehicle Administration Registration, Certificates of Title and Autotheft Act
II Uniform Motor Vehicle Operators' and Chauffeurs' License Act
III Uniform Motor Vehicle Civil Liability Act
IV Uniform Motor Vehicle Safety Responsibility Act
V Uniform Act Regulating Traffic on Highways
VI Manual on Uniform Traffic Control Devices for Streets and Highways

These Conferences offered a wonderful opportunity for pooling information bearing on the street and highway traffic problem obtained from every section of the United States. But the greatest accomplishment to which they can lay claim is the tremendous influence exerted towards establishing uniformity of traffic regulations throughout the country.

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CHAPTER II

TRAFFIC OFFICER CONTROL AT INTERSECTIONS

OFFICER CONTROL IN NEW YORK

As a result of William Phelps Eno's activity in bringing about the inauguration of street traffic regulation in New York at the beginning of the twentieth century, we find the police officer taking an active part in this work.

The establishment of a traffic division for the purpose of regulating traffic was a decided innovation, which, as might have been expected, met with strenuous opposition. After several years, however, when the public became aware of the benefits that resulted from this new activity, opposition began to disappear. In the past, the police power claimed but one function, that of crime prevention. The traffic problem was to add to this the prevention of accidents and the expediting of travel.

In the days when automobiles were the exception, the principal duties of the New York City's meager traffic squad was to preserve the peace among truckmen and teamsters, whose slow-moving vehicles were a constant source of trouble in the free movement of traffic on the heavily traveled thoroughfares. With the appearance of the automobile, the officers believed they saw in this invention a happy solution of their traffic worries. Possessed with a larger carrying capacity and a higher speed, there would naturally follow a greater fluidity of movement; commodities would be transported with greater ease, and in shorter time; and there would be removed forever the blockades and delays that were then the officer's constant worries. It did not require many years to demonstrate the weakness of this analysis.

In a folder published by William Phelps Eno in 1903 we find the officers' duties outlined as follows:

1. To manage the block system.
2. To see that drivers do not break the rules.
3. To exercise careful supervision over cab, hack and truck stands, and over drivers of all numbered, registered, licensed and public vehicles, especially the drivers of cabs and hacks.

4. To see that traffic is not delayed by vehicles loading or unloading, or being backed up to the sidewalk.

Mounted policemen had a definite task mapped out during this early traffic control period. It was their duty to keep the lines of traffic separated, make slow moving vehicles keep near the curb, and force drivers to take their turns properly. They acted as instructors in traffic regulation.

Equipped with bicycles and motorcycles, the policemen were able to catch people who were inclined to speed; and being in a position to work more quickly, they exercised supervision over traffic conditions in general, in case of any emergency.

In 1902, Capt. A. R. Piper, U.S.A., who held the position of Deputy Police Commissioner of New York City, devoted some time studying the methods employed in London to handle their street traffic problem. This study was undertaken for the purpose of organizing a satisfactory street traffic management in the Metropolis. In 1903 Capt. Piper succeeded in having three mounted policemen stationed on Fifth Avenue; and on December 7, 1903, through the influence and activities of Mr. Eno, this number was increased to six. The establishment of the Bureau of Street Traffic followed in April, 1904. The developments that transpired within this period of less than a year might well be considered the "milestone, if not the actual beginning of modern traffic control."

By the end of the year 1908 the Bureau of Street Traffic supervised the activities of the Traffic Squad, which at that time numbered 743 men in all. Of this number, 138 were mounted and 18 were provided with bicycles. It was advocated at this time that although but 7½ per cent of the whole police force was devoted exclusively to traffic duty, all officers should be instructed to acquaint themselves with the essential traffic regulations in order to be in a position to render assistance when occasion demanded.

The traffic officer of this period was expected to meet the following qualifications: Smart appearance and bearing, tact in managing drivers, and a thorough knowledge of the traffic regulations. It was recommended that he should have no other duties, and his tenure of office should be dependent upon efficiency of service, and accompanied with commensurate pay.

WHISTLE SIGNALS

Manual and whistle signals were the first aids utilized in the control of street traffic, and are still used to some extent. In "Street Traffic Regulation" published by W. P. Eno in 1909, the following instructions are recommended for the traffic officers of New York City: "One blast of the police whistle indicates that north and south traffic shall stop and that east and west traffic shall proceed. Two blasts that east and west traffic shall stop and that north and south traffic shall proceed. Three or more blasts is a signal of alarm, and indicates the approach of fire engines or some other danger."

This method of control soon spread to other parts of the country, but with a lack of uniformity in its application.

In some cities, two blasts indicated stopping the north and south traffic and starting the east and west; one blast meaning, STOP for east and west traffic, and GO for north and south traffic. In another system a change in traffic was indicated by a single blast of a whistle after which the officer gave the direction by a manual signal. A third use of the whistle was to stop all traffic, and after allowing sufficient time for movement of pedestrians at crosswalks, the officer started the vehicular traffic by arm or hand signals. This was particularly effective at irregular intersections, and overcame the principal objection to the whistle signal alone. The use of the first or second system described above moves the pedestrian traffic at the same time as vehicular traffic and, at intersections where there is any considerable volume of turning vehicles, it frequently happens that the pedestrians have little opportunity to cross the roadway. Whistle signals, if used, should be arranged so as to provide adequate time between changes of vehicular traffic movement, and for the movement of the pedestrian traffic. According to C. P. Taylor the following meaning is attached to whistle signals:

One blast: North and south traffic stop; east and west traffic go.

Two blasts: East and west traffic stop; north and south traffic go.

Three or more blasts: Police or fire apparatus coming.

In the Chicago district, however, the meaning of the one and two blasts was exactly reversed.

The significance of one or two blasts of the whistle to indicate the direction of traffic is becoming extinct because of the possibility of confusion. A blast or two of the whistle has almost everywhere come to mean that a change is about to be made and that traffic should watch for signals. A rapid succession of short, sharp blasts is accepted as a special call for giving attention to the officer who has some unusual direction to make, such as to clear the intersection for police or fire equipment, or to caution or arrest a violator.

HAND SIGNALLING

Hand signalling is classified by C. P. Taylor in "Traffic Officer's Training Manual" as the Eastern System and the Western System. According to the latter, the officer takes a position of the body paralleling the flow of traffic, at the same time extending both arms in a horizontal position. Besides giving a plain indication of the direction the traffic is to follow, he gives the appearance of a barricade to the vehicles moving in the other directions. As the traffic gets under way, he drops his arms, or gives further directions to the traffic flow, but always maintaining his body in the same relative position until the time when a change of position is necessary.

The Eastern System, originated with Captain Bernard Hoppe of the Boston Traffic Police Department, and may be described as follows:

"To stop traffic from the right: Turn the body slightly to the right, look over the right shoulder, raise the right arm to an angle of forty-five degrees, direct the palm of the hand toward the vehicle to be stopped. Hold until signal is obeyed.

"To release traffic from the right: Look over right shoulder, raise are to an angle of forty-five degrees, palm front, and swing arm to the left across face.

"To stop traffic from the front: Raise left arm at an angle of forty-five degrees to the front, with palm toward the vehicle to be stopped. Hold until signal is obeyed.

"To release traffic from the front: Raise left arm at an angle of forty-five degrees to the front, with back of hand toward the vehicle, and swing hand back over left shoulder.

"To warn pedestrians right and left: Raise both arms horizontal with shoulder, palms toward the pedestrians.

"To release pedestrians right and left: Raise both arms horizontal with shoulders, palm front, and swing arms across chest."

Among the decided advantages that this latter method has over others, two may be cited. (a) Since the position of the body means nothing, an officer may take any position within the intersection which he finds most advantageous. (b) Each stream of traffic receives its own individual STOP and GO signal, thus giving the officer complete control over every movement.

Where the Western method is used, it is necessary to employ the Eastern signal for directing turns.

In either system, once flow has started, officers conduct themselves differently. Some continually beckon, and others stand at ease, as the individual finds it most convenient and most effective.

Even after the introduction of the semaphore and the latest developments of the automatic signal, hand signalling by the officer must remain an important method of cummunication with the different elements of highway traffic.

LOCATION OF OFFICER AT INTERSECTION

The location of the traffic officer will naturally vary with the character of the intersection. In the case of the ordinary right-angle intersection only two positions have proved popular with police officers.

In the one case the officer places himself at the center of the intersection. This position has certain decided advantages:

1. It is orthodox - operators and pedestrians expect to find an officer there.
2. Every one's view of the officer is equally good.

The disadvantages connected with this position are as follows:

1. The officer, himself, can obtain a full view of only two entrances to the intersection without turning around bodily or looking over his shoulder.
2. He is seriously exposed to danger and obnoxious gases.

3. He forms a traffic obstruction, and drivers are often uncertain whether they should make a left turn in front of or behind him.

4. He is too accessible to operators of vehicles, their insistent stops to put questions to him often causing much trouble.

5. He is too inaccessible for questioning by pedestrians.

In another position, less frequently used, the officer located himself at the intersection of the center line of one of the streets and a projected curb line.

In this position the officer can view all entrances without turning around; he is less exposed to danger; he forms little if any obstruction to traffic, and his position for questioning by any drivers or pedestrians who can reach him is good. On the other hand, the officer thus placed is in an unfavorable position to indicate the direction for traffic flow by paralleling his body with it, which is accepted practice in many places.

ADVANTAGES OF OFFICER CONTROL

In the early stages of motor vehicle travel the traffic officer standing in the roadway directing traffic symbolized to the layman the whole of traffic control. Even today, in the presence of our modern development of traffic control systems, the officer, under certain circumstances, constitutes an important element in orderly street traffic movement.

The characteristics of officer control may be listed as follows:

1. The traffic officer is intelligent and is able to take advantage of small breaks in heavy streams of traffic to accommodate the light cross traffic with the least inconvenience; he can use brain power, which is better than mechanical power.

2. He has flexibility. His time periods may be adjusted to conform to the variations in traffic density and give to each street that proportion of time which it demands.

3. He has the ability to dispatch scattered traffic most effectively.

4. He is obeyed readily by both motorist and pedestrian.

5. He can expedite the movement of street cars when loaded and ready to go better than a mechanical device.

6. He can aid turning traffic, particularly left turning traffic, often permitting it to weave through traffic from the opposite direction without entirely stopping either line.

7. He can very readily control any unusual condition or emergency.

DISADVANTAGES OF OFFICER CONTROL

Allowing for the excellent service rendered by the traffic officer in directing vehicular and pedestrian traffic, yet, when we consider the many demands made upon him, and in particular, when placed side by side with the advances made in the use of the automatic signal, certain disadvantages and limitations of the officer become apparent.

1. It is practically impossible to coordinate his work with the efforts of officers on all four sides of him, one or more blocks away. Impossibility of coordination by traffic officers is the main reason why a proper electrical control system can, if conditions are favorable, usually handle traffic in an important business district more expeditiously and efficiently than can even first class officers, working as isolated individuals.

2. The officer is often difficult to locate quickly on account of his rather low visibility. If raised above the street level by means of a platform, he is then prevented from conveniently performing certain functions which call for mobility on his part.

3. If the officer uses a semaphore, there is a strong tendency for him to become merely a human machine. One of his greatest assets as an intelligent being, is thereby greatly jeopardized.

4. The traffic officer is frequently called upon to give information, to serve as law enforcement officer by tagging or arresting violators, to attend to emergency cases, such as fire and accidents, in which cases traffic is entirely without supervision and control. Thus the officer is removed from the principal function for which he was primarily stationed at the intersection.

5. Inefficient officers, or men newly assigned to traffic duties, must necessarily handle their corners inefficiently.

6. Officer control suffers in comparison with electrical control in the matter of cost.

7. His hand signals tend to be directed to the individual motorist rather than to groups of motorists, thereby causing traffic to move more slowly through the intersection than would be the case if signal lights were used.

8. The same signal does not always mean the same thing. Each officer has his own personal characteristics, hence, the motorist is a little more hesitant at intersections under the control of a traffic officer.

9. The traffic officer has a tendency to do the thinking for the motorist. Drivers tend to rely entirely upon the judgment of the officer, and they cease to do their own thinking.

10. The psychological effect on a considerable percentage of drivers is such as to make them more timid and hesitant about moving into an intersection where an officer is stationed than if the intersection is controlled by a traffic light.

11. The traffic officer is prone to wait for stragglers, instead of turning promptly to waiting traffic.

12. Like any other human being, the traffic officer cannot work at his highest efficiency continuously. Neither can he keep his mind continuously on his work. Therefore, the all-day average traffic regulation by the officer cannot be as good as his best.

13. He cannot see in all directions at once. His mind cannot take into consideration all of the conditions prevailing at complex intersections.

14. Where traffic control is manual in character, and both pedestrian and vehicular traffic are heavy, the normal tendency of officers under such conditions is to favor vehicular requirements, inasmuch as delays to this class of traffic are more apparent than delays to pedestrians.

15. The tendency is to develop an automatic practice in which the officer really thinks very little.

TRAINING OF THE MODERN TRAFFIC OFFICER

The police problem in general covers the fields of crime, vice and traffic; and the relative importance of these, as pertains to mortality rates can be found from comparative figures contained in the 1934 edition of Accident Facts, published by the National Safety Council. Homocides numbered 11,459; suicides, 21,731; motor vehicle fatalities, 29,451.

The important role which the traffic officer holds in the solution of this problem, has been given more consideration in the last decade. This changed demand for a highly trained traffic officer, distinct from the usual police officer of the past, arises from very fundamentally changed social conditions in which the previous type of officer was unable to function satisfactorily.

Legal restrictions in the past were few and fundamental, very largely involving those offenses which were bad in themselves, and easily recognized as such. The police were concerned chiefly with the enforcement of laws involving fundamental rights of persons and property. The officer's contacts were more frequently with the hardened criminal element, whose crime was fundamental and generally accepted as such.

Recent years have brought about some very far-reaching changes. The personal rights of the citizen have become submerged in the community rights of society. As a result of the many complicated restrictions, the citizen's activities are carefully hemmed in by regulations which make certain acts unlawful; although these may not in themselves be bad.

In every community there is a substantial percentage of the population which is definitely anti-social in its attitudes, and which has a willful and reckless disregard for public decencies and public safety in regard to street use. This class of individuals must be apprehended and severely punished. They constitute a direct social menace. There is an even larger percentage composed of individuals who are normally law-abiding citizens, but who, through ignorance, carelessness, or a feeling that traffic rules and regulations are of minor importance, are more or less constantly violating essential rules and regulations designed for convenient and safe street use. This class must be sought out and, through warnings or punishments, when necessary, informed and guided to a more correct attitude with respect to the proprieties of using the public thorofares.

Traffic work has become quite complex in character and is rapidly changing, and the traffic officer has a task of

THE SEMAPHORE

The first record of the use of a semaphore for the control of street traffic dates back to the middle of December, 1868, when an installation was made at the junction of Parliament Street and Bridges Street, Westminster, London, England. The device was put into operation for the first time at the beginning of the parliamentary session of that year.

In 1866, a Select Committee had suggested that a modification of the railway signalling system be adapted to street traffic. But it was left to private enterprise to develop the idea which was later patented by a firm of engineers.

This semaphore had a total height of twenty-two feet. Three arms were attached at a height of eighteen feet from the ground. These were raised to the horizontal position or lowered by the pulling of a handle, all of the arms acting simultaneously. After dark, the raised arm showed a red light, and when dropped, a green light.

In March of 1869, the question was brought to the Secretary of State through the House of Commons "whether the structure called a semaphore on the crossing near the House of Parliament was conducive to the safety of the Public, and, if not, whether he would give instruction for its removal?"

Although one constable had been killed while operating the semaphore in question, and two others received minor injuries, the Commissioner, after further study into the matter, was convinced of its usefulness, and recommended that its use be extended to other parts of the Metropolis.

Notwithstanding that the Home Office authorized the Commissioner to induce the Westminster District Board of Works to have an improved design of semaphore erected, the Board which had been advocating the removal of the old semaphore since its erection, finally attained its objective, with the result that it was dismantled in 1872. According to the original agreement at the time of the erection of the semaphore, the inventors were called upon to pay half the expenses, amounting to over three hundred pounds, covering the cost of semaphore and cost of operation.

The mechanical semaphore first appeared in the United States about the year 1913. The Detroit semaphore consisted of four revolving blades set at right angles at the top of a light portable standard, the blades showing the words GO and STOP on alternate faces, and painted appropriately green and red. At night, the arms were surmounted by a signal lantern of the railroad type, with red and green lights. With a movement of only a quarter of a turn necessary at a time, the semaphore arms were very easily manipulated by the officer, which fact served as an encouragement to the officer to frequent changes and thus a consequent reduction of delay to vehicles.

As might have been expected, the early devices were somewhat crude in character. In at least oné city, large beach umbrellas were supported on light standards and had the words STOP and GO painted at the proper points on the canvas. The traffic officer stood beneath the umbrella and turned it through angles of ninety degrees by a handle attached to the stick.

In the summer of 1913, semaphore signals for traffic regulation were installed in Philadelphia, at Chestnut and Broad Streets. Two arms were used, one marked STOP and the other CLOSED. They were manipulated by a local traffic policeman, and were considered rather successful because of their distant visibility. They were used to replace the "whistle-and-beckon method ".

Electric semaphore signals were recommended in a report of the Board of Supervising Engineers for Chicago's congested traffic for the heaviest crossings in Chicago, to be operated by a traffic officer occupying a raised position at the curb.

In 1915 semaphores with automatic whistles were installed in San Francisco. They were arranged so as to permit of electrical control from the officer's stand. The device consisted of a double-pointed arrow bearing the word STOP on either face, and which could be turned through ninety degrees by a small one hundred and ten-volt motor mounted in a metal box just above. The motor also operated a police whistle which sounded two blasts as the arrow pointed one way, and a single blast when it returned to the opposite direction.

When the crossing was to be cleared for an emergency, the arrow was made to revolve continuously and the whistle blew until it was shut off. At nights, the arrow was lighted by two forty-watt tungsten lamps; and a third lamp, located in the red globe below, was automatically put in the circuit when the alarm signal was given. The switch box

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CHAPTER III

AUTOMATIC TRAFFIC CONTROL SIGNALS

Highway traffic signals, according to the Manual on Uniform Traffic Control Devices for Streets and Highways, of the National Conference on Street and Highway Traffic Safety of 1934, include all power-operated devices using light, by which traffic is warned or is directed to take some specific action. Thus, they are distinguished from illuminated signs or from signs with luminous buttons.

Signals are classified functionally and physically as follows:

1. Traffic control signals
   (a) Fixed-time
   (b) Traffic actuated

2. Other Signals
   (a) Flashing caution
   (b) Flashing stop
   (c) Stated speed
   (d) Train approach

As the present chapter is concerned especially with traffic control signals, it will be of interest to study the following definitions as they appeared chronologically in various publications.

From Street Traffic Control Problems of San Francisco, 1927.

> "Traffic Stop and Go signals are designed for the purpose of alternating the movements of traffic at those intersections where otherwise confusion and congestion would result."

Model Municipal Traffic Ordinance of 1928.

> "A traffic control signal is any device using colored lights and words, or any convention thereof, whether manually, electrically or mechanically operated, by which traffic is alternately directed to stop and proceed."

Massachusetts Traffic Code, Traffic Bulletin No. 2, 1929.

more signals of similar design were added, these being interconnected and under manual control. The signals were staggered, giving a certain degree of progressive movement of traffic.

In December, 1920, Detroit improved upon its tower installation at Michigan and Woodward Avenues, which had been in use as a form of semaphore for the past three years. They equipped it with powerful floodlight projectors twelve inches in diameter and carrying two hundred and fifty-watt lamps. The lights were stationed on the roof of the booth and were manually controlled.

In 1920, New York erected its first traffic towers on Fifth Avenue, consisting of wooden booths, supported on angle-iron standards. These were replaced by seven bronze towers in 1922. New York's signals were two-directional along Fifth Avenue. They consisted of sixteen-inch floodlight projectors with five hundred-watt lamps. The signals in other cities were of the four-directional type.

In February, 1921, six traffic towers were installed in Knoxville, Tennessee. They were operated independently,

Syracuse, New York, had a four-way signal, similar to those used at the present time, installed in December, 1922.

Philadelphia erected a unique signal light which operated during the months of May and June of 1924. The projected plan called for the installation at a point on the City Hall, about three hundred and fifty feet above the pavement, of four 300,000,000 candle-power searchlights, one on each face of the building. In order to aid visibility, floodlights of 500,000 candle-power were to be placed on each side of the building near the street level. Only one of the large searchlights was actually erected, and the smaller lights were put into operation on the three other sides; this was done because of the lack of immediate funds.

The master control signal consisted of one light, orange-red in color, and signals were given by turning this light on and off. There were no variations of colors.

The primary function of the master light was to signal the policemen rather than the individual drivers. When the red light showed, all traffic in both directions on the street in question stopped, and the cross-streets were opened, and vice versa.

The time interval of the master signal was based on the heaviest cross-street. Comparatively short intervals were used on Market Street, where surface cars operated, and longer intervals prevailed on Broad Street. It was planned to regulate the searchlights by a mechanism made of two discs. As portions of these discs in relation to each other were changed, the lengths of time during which there would be no light were determined. The intervals could be changed several times during the day as the traffic demanded.

This installation resulted in synchronized control in keeping the street cars separated in small groups on Market Street, instead of allowing an accumulation of cars waiting to cross the busiest intersections. The vehicular traffic movement was likewise synchronized for nine miles on Broad Street, north and south, and for two miles east and west on Market Street.

With the removal of the hand semaphores at the individual intersections, the cross traffic was found without control. This held likewise for the traffic moving away from the master lights, since these vehicles were left without instructions how to act, other than those received from the officers on duty. Due to a lack of further appropriations these signals ceased to function July 1, 1924.

On December 5, 1925, Minneapolis put into operation thirty-six automatic traffic control signals. The signal was placed between the tracks of the street railway, and consisted of a square post mounted on a cast steel plate flush with the pavement. Underneath this plate an arrangement of springs held the post in a vertical position, the springs being flexible enough permitting the post to yield if struck by a vehicle. The words STOP and GO were cut through the metal sides, and the openings were covered with glass so that the flashing on and off of the lights inside the post illuminated the words in different colors. Because of its flexible feature, this signal was called "The American Bobby."

The main purpose of the lights on the early signal towers was to coordinate the movement of the traffic officers, in order that all the officers on the thoroughfare might give their signals simultaneously. The towers were placed at good distances apart, for which reason the colored lights had to be visible to the operators of adjacent towers, as well as to the officers on the ground, at distances of about a quarter of a mile or more.

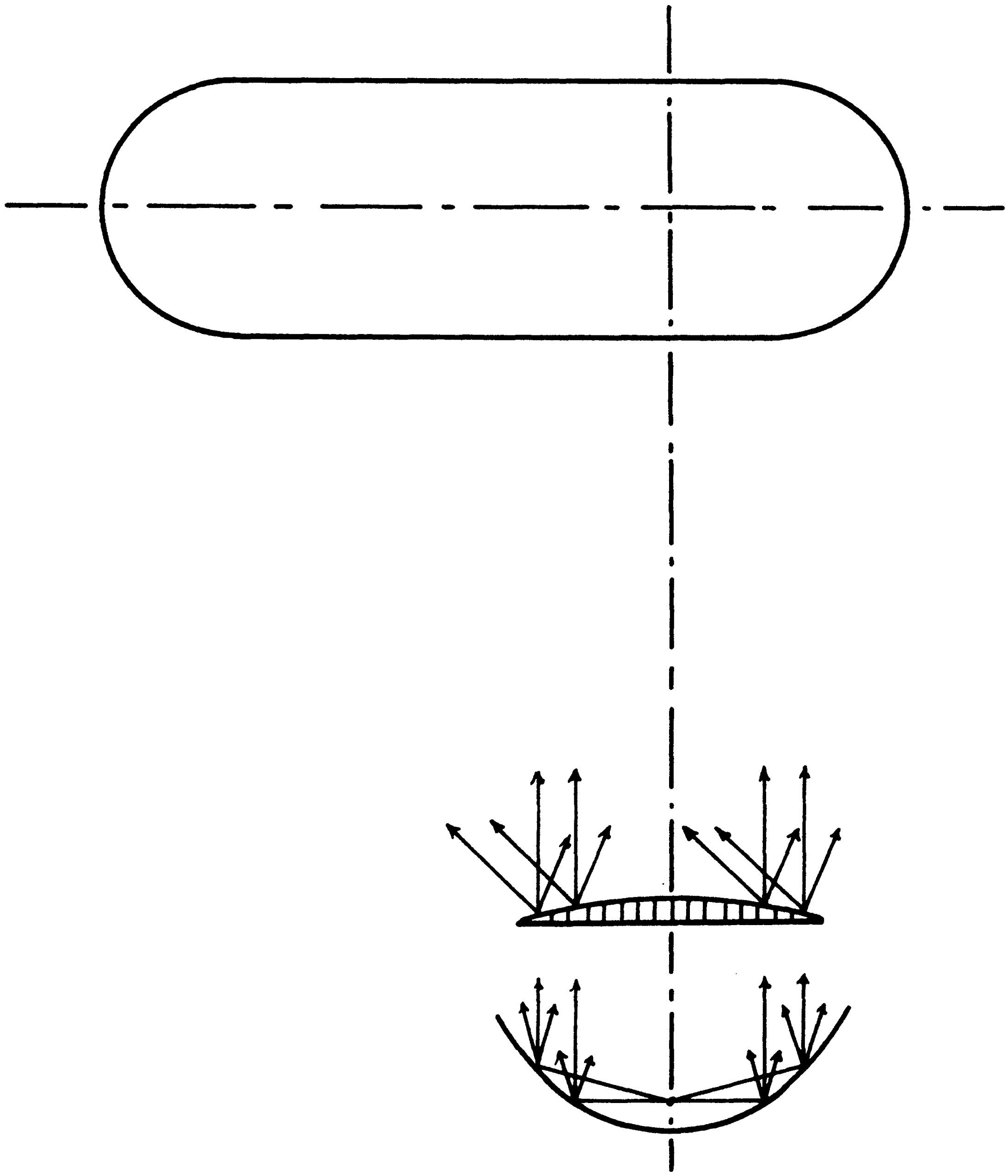

Fig. 3 -- Flutes of asymmetrical contour refract more of the light to one side of the axis than the other

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illuminated disc showing a pronounced "sparkle" when viewed from different angles.

This new type of lens became quite popular because of its utility and economy. There followed a great impetus in the industry, with the result that this original lens, which might be considered the parent of practically all existing lenses, was subject to further investigation and made more efficient by eliminating the spherical dispersion, and providing for a more selective distribution of light. As shown in Figure 2, the collecting lens, or reflector, sends the light in a relatively narrow beam to the distributing lens which,by the introduction of symmetrical flutes, causes a refraction of the light, giving almost any spread desired in a horizontal direction only, where the light becomes more effective.

By the use of flutes of asymmetrical contour, there results an unequal distribution, directing more light to one side than to another. Figure 3 is an application of this principle.

The most efficient beam is somewhat triangular in shape; by means of vertical, diagonal, or horizontal cylinders or prisms, the light is directed both vertically and horizontally, as shown in Figure 4.

The requirements of an efficient signal light as to spread and visibility are shown in Figures 5 and 6.

Figure 7 shows the minimum candle power necessary to obtain sufficient signal brightness, both during the day and night, and satisfactory for both drivers and pedestrians.

Thus shortly prior to 1926 a traffic signal was perfected that gave a clear intensive and unmistakable signal indication through a wide angle, under bright sunlight conditions, as well as at night, a signal presenting a bright surface through a relatively narrow vertical angle of from ten to fourteen degrees, and through a wide horizontal angle of from sixty-five to eighty degrees or more. This signal gave a commanding brightness for a minimum lamp wattage, and directed different intensities at the several angles from which it was observed -- a greater density at higher angles for the automobile driver, and lower brightness but wider angles for the pedestrian.

Whilst producing a signal that meets all these requirements, it became necessary to eliminate the so-called "sun phantom," which is a false indication that appears early in

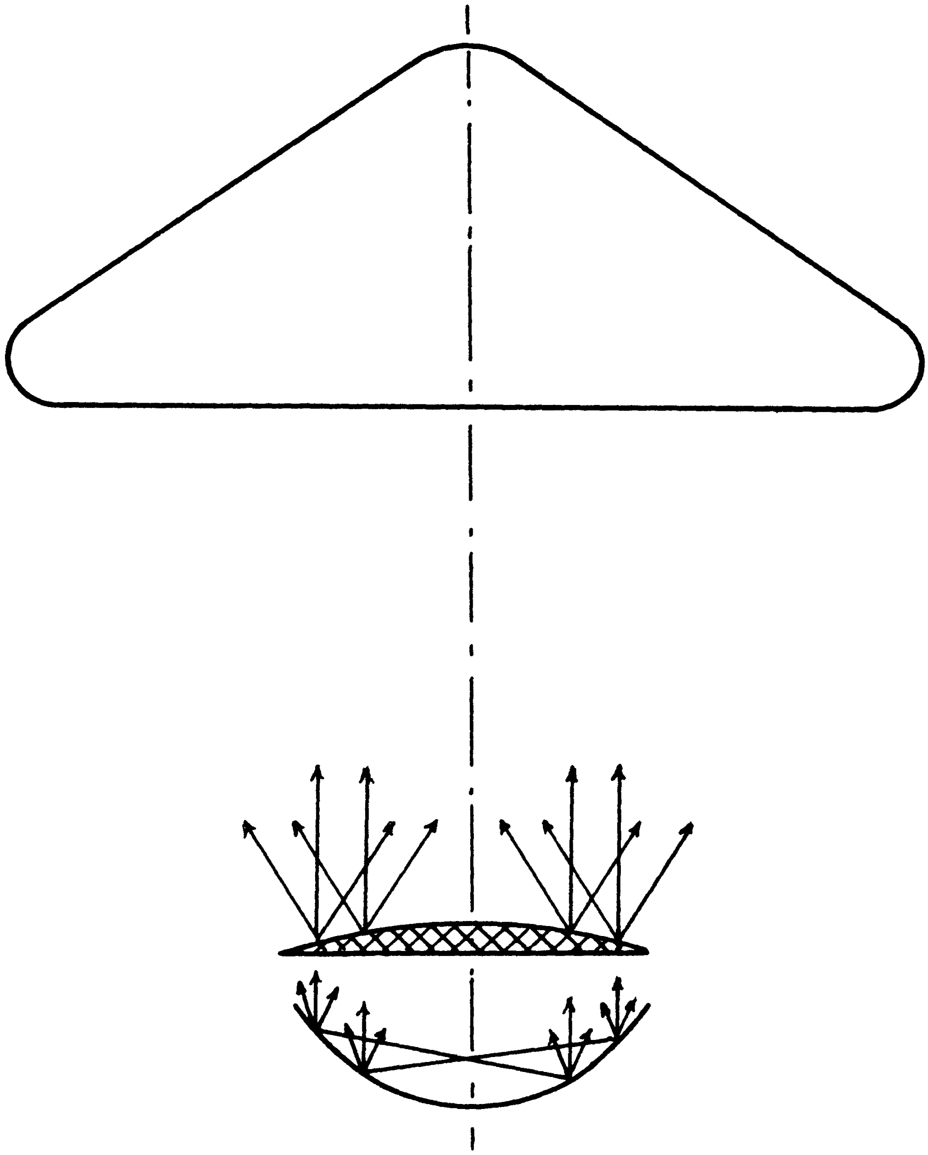

Fig. 4 -- Horizontal refracting prisms combined with vertical flutes direct downward a portion of the light at wider angles

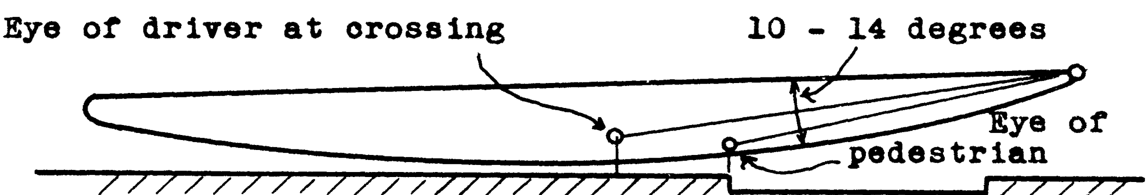

Fig. 5 -- Vertical angles through which signal is viewed

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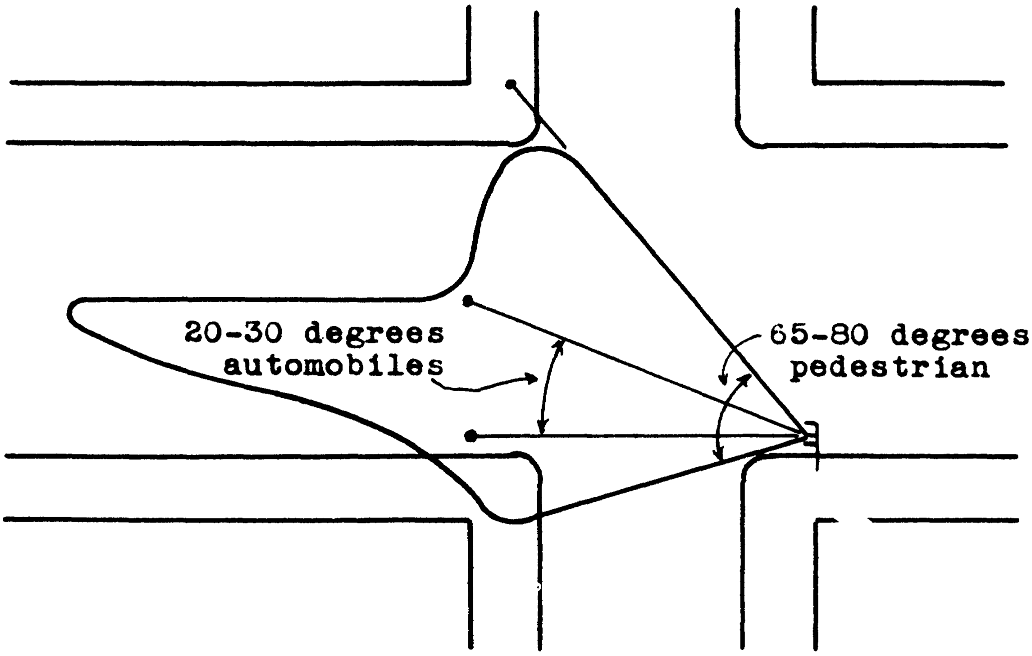

Fig. 6 -- Horizontal angle through which signal is viewed

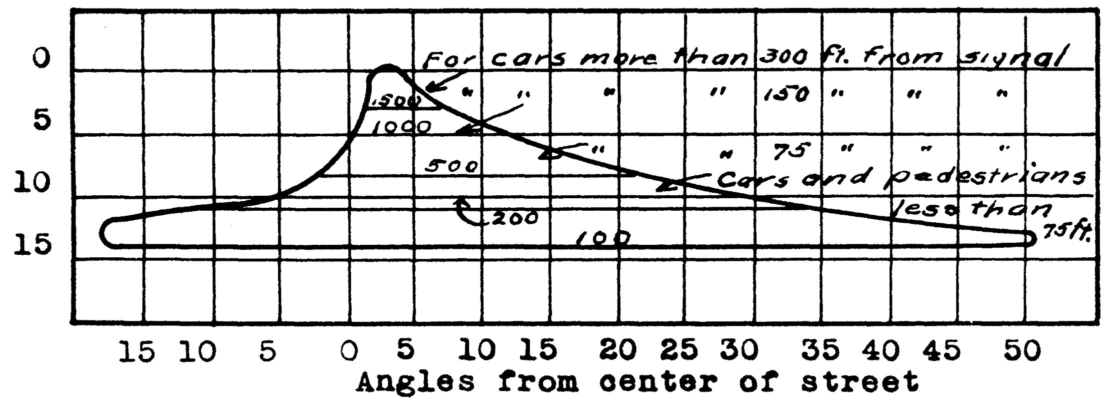

Fig. 7 -- Cross-section of beam showing minimum candle-power values for effective bracket signal

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the morning or late in the afternoon when traveling away from the sun, with the rays shining into the signal ahead. With the older type of a deep parabolic reflector, it was impossible to determine which of the lenses was illuminated. By employing a shallow parabolic reflector, united at the focal line with a rippled reverse spherical section, the sun rays are not reflected, thus making it possible to determine at all times of the day which of the lenses is giving its signal indication.

From an optical viewpoint, signals became pretty well standardized, but mechanically, they took on many forms depending upon varying traffic demands, physical conditions of installation and the ideas of local officials.

TYPES AND INSTALLATION OF SIGNALS

Depending upon the existing conditions and the ideas of municipal authorities as to what form of signals is desirable, various combinations of types and locations of traffic control signals are in use, as indicated below:

1. One-way signals mounted on the far right corners of the intersection, one for each line of vehicular traffic. This arrangement is very popular because of the decided advantages offered from the point of view of visibility:

(a) The axis of vision of the vehicle driver is directly in line with the signal.

(b) Each signal is close to the normal line of sight.

(c) The light is required to be bent through only a small angle, permitting a maximum brightness for a given wattage.

(d) It furnishes a very definite signal for pedestrians, since there is one unit directly in front of each line of traffic, and at an angle of forty-five degrees for the other line.

(e) It is easily seen by automobile drivers waiting for a left turn.

(f) Street cars do not obstruct the view of the signal.

(g) The signal is readily reached for maintenance.

The corner post signals may be either of the mast arm or bracket type, the latter being either horizontal or vertical; or, of the post type, with the lights mounted directly on top in a vertical position. The horizontal type has the slight disadvantage that it must have a clearance of from fourteen to fifteen feet, making it somewhat less effective because of the greater vertical angle at which it is seen.

2. Four one-way signals may be located on the near right side of the intersection, but this position has very little to recommend itself. The driver has the signal nearer to him when approaching the intersection, but the occupants of the waiting vehicles are in no position to see the change of lights, particularly when there are vehicles parked near the intersection.

3. With the two-way (180-degree) signal on the near right corners, the driver of a waiting vehicle may view the signal by looking diagonally to the left at an angle of forty-five degrees; but even this view is frequently obstructed by a standing street car, or a waiting car when there are two or more lanes of traffic in one direction. In this case, an attempt is made to give both vehicle drivers and pedestrians two different signals to look at. Notwithstanding this extra light, the additional expense thus incurred, both for initial installation and for maintenance, does not give it a decided advantage to make it comparable with other arrangements.

4. Two-way signals (180 degrees) located on the far right corners. This installation becomes practically the same as that of one-way units at the far right corners, since in no case is the vision of either pedestrian or vehicle driver bettered. The only advantage of helping the pedestrian walking down the left hand side walk is not very appreciable, since by the time he has reached the signal and passed it, the indication may have changed.

5. Four two-way (90 degree) signals on the far right corners. This arrangement is an improvement over the one-way signal, similarly placed, by affording the pedestrian a signal in direct line of vision at all times when crossing the intersection. This type of installation is perhaps the perfect installation, but it is questionable whether or not the increased installation cost and the double maintenance cost is worth the gain. It is used in the case of heavy pedestrian traffic.

6. Three-way signals at each corner. Attempts at this arrangement have been made, placing the signals either at the near or far corners, it making little difference,

since there are always two or more signals for both the vehicle driver and the pedestrian. Signals thus placed tend to be more confusing than helpful, since the less intelligent driver is apt to look for any green signal and interpret it to mean GO, regardless of whether or not it is displayed in the line of traffic in which he is driving.

7. One four-way signal at the center of the intersection. If of the pedestal type, the signal is mounted in the roadway from eight to nine feet high. In this form it gives perfect vision to the vehicle driver and a reasonably good vision to the pedestrian, but presents an undesirable obstruction to the moving traffic. If the signals are suspended, several disadvantages become manifest:

(a) They are apt to be out of the line of vision of the vehicle driver, which is confined by the automobile sun visors; traffic waiting to make a left turn is one group which suffers from this difficulty of seeing the signals.

(b) The light must be directed downward through large angles, thus giving lower signal brightness for a given lamp wattage.

(c) Both the GO and STOP signals are often visible to pedestrians on the same unit, thereby causing confusion.

(d) Street cars may obstruct the vision of the signal.

(e) The maintenance is more costly and more difficult.

(f) During the bright sunlight it is often difficult tc determine which light is burning.

The only advantage claimed for this type is its economy of installation and operation.

8. Two four-way signals on diagonal corners. Such an installation has as object to give double vision to both vehicle driver and pedestrian, and a lower installation cost as compared with the four-way signals with faces ninety degrees apart.

The 1934 Manual makes the following recommendations relative to the installation and types of signals:

(a) A signal installation shall control traffic only at the intersection where the installation is located, thus avoiding the danger of expecting cross traffic at intervening unsignalized intersections to be governed by such signals.

(b) Signal faces shall normally be located to give approaching vehicular traffic a control indication from the far right corner of the intersection. Auxiliary face locations may be called for in the case of a long intersection, an obstructed view, or irregular intersections.

(c) There shall be at least one signal face for the control of traffic on each street entering the intersection, with additional faces for pedestrian control, in front of each approved line of pedestrians crossing, if the number of pedestrians is appreciable, or if the hazard to even a few pedestrians is considerable. Recent analysis indicates a trend toward two faces per corner.

(d) One signal for each direction of approaching vehicles shall be located as near as is practicable to the curb line of the street whose traffic it controls.

(e) The height of signals. The bottom of the housing shall not be less than eight feet or more than ten feet above the sidewalk, in case of the post type, and a minimum of fourteen feet six inches for the bracket or mast-arm type, which must be extended over the moving traffic.

WARRANTS FOR INSTALLATION

The conditions or "warrants" required for the installation and operation of fixed-time traffic control signals, are clearly set forth in the 1934 Manual.

1. Minimum vehicular volume.

A total vehicular volume entering the intersection from all directions to average at least one thousand vehicles per hour for eight hours, of which an average of at least two hundred and fifty vehicles per hour for eight hours enter from the minor street.

When this vehicular volume falls below five hundred vehicles per hour for a period of two hours or more, a fixed-time signal should be operated as a caution or stop signal, or a combination thereof.

When several moving lanes are to be found on one or more streets, the vehicle volume should be increased beyond what is specified above. A suggested table for these corrections is to be found in the New Jersey Traffic Code, No. 1, 1931.

The vehicular counts for this study may be made for fifteen-minute periods, or preferably for five-minute periods, and the counts should be of sufficient duration so as to cover that portion of the day during which the signals are to be operated on a STOP and GO basis.

2. Heavy Left-Turn Warrant.
The minimum requirements are as follows:

(a) Total vehicular volume entering the intersection to average at least one thousand vehicles per hour for eight hours.

(b) The vehicular volume making a left turn must be such to cause unreasonable delays. For the usual intersection, this would call for at least an average of five vehicles per minute for the heaviest traffic hour which should cross through an opposing stream of at least equal volume.

3. Pedestrian Volume Warrant.
This calls for the following minimum counts.

(a) Pedestrian volume crossing the major street to average at least two hundred persons per hour for at least four hours per day.

(b) Vehicular traffic from the major street to average at least seven hundred and fifty vehicles per hour for the same four hours.

(c) Vehicular speeds during the four hours must frequently exceed fifteen miles per hour.

When for two hours or more the vehicular traffic drops below three hundred and seventy-five vehicles per hour on the major street, or the pedestrian volume crossing the major street falls below one hundred persons per hour, the signal shall not be operated as a fixed-time signal.

4. Coordinated Movement Warrant.
A fixed-time signal which would not be justified by any other warrant may be permitted as a "spacing" signal, forming part of a coordinated signal system, for the purpose of effectively regulating the speed or maintaining the proper grouping of vehicles. Such "spacing" signals are not ordinarily warranted unless the unsignalized distance is more than two thousand feet.

5. Through STOP Street Warrant.

A fixed-time traffic control signal may be warranted on a through STOP street:

(a) To afford a reasonable crossing interval for pedestrians or vehicles when the through STOP street carried a very heavy vehicular traffic.

(b) As a part of a speed-controlling coordinated signal system along a through STOP street to accommodate the pedestrian and vehicular cross traffic.

The principle of this warrant may also be applied to certain thoroughfares which are not through STOP streets.

6. Accident Hazard Warrant.

Installation of signals for this purpose may be justified where:

(a) Five or more accidents of types susceptible of correction by a traffic control signal have occurred within a twelve month period, each accident involving personal injury or property damage to an apparent extent of $50.00 or more.

(b) Adequate trial, with satisfactory observance and enforcement of less restrictive remedies have failed to reduce the accident toll.

When the signals are installed because of accident hazards the total cycle should be as short as possible to serve the traffic approaching during the heaviest traffic hour.

Traffic control signals may be expected to eliminate or materially reduce the number and seriousness of the following types of accidents:

(a) Those involving collisions between vehicles on intersecting streets which will move on separate GO intervals.

(b) Those involving pedestrians and vehicles which will move during different GO intervals - provided most pedestrians obey the signals.

(c) Those between straight moving and left turning vehicles where these are to move on separate GO intervals.

(d) Those involving excessive speed in cases where coordination restricts speed to a reasonable rate.

Reduction of the following accidents cannot be expected by traffic control signals:

(a) Rear-end collisions which often increase after installation.

(b) Collisions between vehicles proceeding in the same or opposite directions, one of which makes a turn across the path of the other.

(c) Accidents involving pedestrians and turning vehicles, both moving on the same GO interval.

(d) Other types of pedestrian accidents, in the absence of pedestrian observance of signals.

In case of doubt as to whether installation is justified because of any of these warrants, other remedial measures might be reasonably tried. Such measures may be: Caution, slow, stated speed and stop signs or signals, laning or otherwise organizing traffic movement, safety zones, other traffic islands.

7. Combination of Warrants. -- Other Factors.

Exceptional cases may present themselves where no one warrant is fully satisfied, but two or more warrants are nearly satisfied. Besides, there may be other factors which may influence the decision, such as:

(a) A sudden change from rural conditions, where relatively high speeds were safe, to those of a busy urban business district.

(b) Extreme width of roadway which pedestrians are obliged to cross.

(c) Predominance of especially handicapped pedestrians.

(d) At the bottom of a steep hill.

CHOICE OF MECHANISMS

After installation of signals appears to be justified on the basis of the warrants here enumerated, a choice of several mechanisms may be made.

(a) A nor-synchronous fixed-time controller, which is suitable only for relatively unimportant isolated intersections warranting signalization, where coordination with other signals is very unlikely, and where the fixed lengths of cycle and intervals will be tolerable during all hours of traffic control operation.

(b) A program type of fixed-time controller which provides for a limited number of changes in cycle length and in the proportions allotted to the GO intervals. Such controllers may be used at isolated sections warranting signalization where there is little likelihood of future coordination with other signals, where the traffic demands vary for different periods of the day; and where with such a program, delays are not unreasonable.

(c) A synchronous type of fixed-time traffic controller for isolated intersections, involving the use of a synchronous motor. This type permits of a design capable of providing for desirable flexibility for normal intersections covering the variation in the total cycle, the choice of variable length of intervals, and the possibility of having at least six separate intervals or periods.

Such controllers should be used at isolated intersections warranting signalization where

(1) Coordination with one or more other signal installations is likely, but not interconnected with a master control.

(2) Where fixed length of cycle and intervals will be tolerable during all hours of traffic control operation.

(d) Controllers providing for coordination, whether by non-interconnected synchronous motors or by the use of a master controller interconnected to local controllers at each signal installation.

Factors to be considered in this choice are:

(1) The volume of traffic involved.

(2) Variation in traffic volume.

(3) Variations between traffic in the different directions.

(4) Economic factors.

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CHAPTER IV

TRAFFIC SIGNAL COLORS

MEANINGS ATTACHED TO TRAFFIC SIGNAL COLORS

With the early application of colored lights for traffic signals it was quite natural to find a considerable variation in the use of the different colors, with the result that lack of uniformity presented a rather serious problem in the effective use of this new device.

After years of experimenting with colored lights for their signal systems the railroads had arrived at the following standards:

A RED light is a very definite order to the engineer to stop.

AMBER is a warning to an engineer to proceed with caution; it marks the place where slow speed is necessary.

GREEN signifies that the track is clear and permits the engineer to proceed freely.

Prior to 1920, red was the only color used for traffic signals which had anything like a universally accepted meaning - that of danger. Yet, a frequent use of this color carried with it a message to proceed with caution. This led to a greater or less indifference on the part of the public in the proper observance of this signal.

Green lights were coming into frequent use, but there was no uniformity with respect to the exact meaning of this color in different localities. Whereas, in some places, the use of a green light on the highways was similar to that on the railroads - to indicate a clear road ahead - it was sometimes used as a warning sign - to proceed with caution.

White lights, which are generally used for the purpose of illumination, were employed in some instances as signals to proceed or to go with caution, with the word SLOW painted upon a large globe.

The lights installed in the early traffic towers of New York carried the following messages:

Amber -- GO - north-south
Green -- STOP - north-south
Red -- CLEAR INTERSECTION

The signal lights of Detroit, Knoxville, and Houston gave the following messages:

Green -- GO
Red -- STOP
Amber -- CAUTION

The Public Safety Section of the National Safety Congress, at its meeting in Milwaukee in 1920, received a report from a committee on this subject, with the recommendation that a change in the use of colors is desirable that will limit the use of red to places of danger and that provision be made for the choice of some other color to be used as a warning or caution signal.

The American Association of State Highway Officials in December, 1920, made the following recommendation:

"Red, indicating first degree danger, to be used only at railroad crossings, dead ends of roads, or lift bridges. All traffic to stop and proceed only when nature of passing the danger or of overcoming it has been ascertained.

"Yellow, indicating second degree danger at curves and grades; yellow would indicate a danger where the driver must slow down and proceed with caution.

"Green, indicating moving of traffic only, and to be used at road intersections."

During the years 1923 and 1924 some headway was made in this new field of traffic signalling, and practically all new installations adopted the colors as used in Detroit and Houston. The first National Conference on Street and Highway Safety held in 1924 made the following recommendation for luminous signs and signals:

Red, to indicate STOP.
Green, to indicate PROCEED
Yellow, to indicate CAUTION as at curves.

Purple, or some other color, as a special cautionary indication at cross roads.

Investigations conducted by the Bureau of Standards, Department of Commerce in 1924 demonstrated that red signal lights are most easily distinguished from other colors at a distance, and require the lowest light intensity for unmistakable recognition. Green signals came second on the list of colored lights easy to identify; but for street traffic, a yellow green is considered preferable to the blue green used on the railroads. Blue ranked third on the list, but was found to require the highest intensity. The railroad yellows, it was found, were often mistaken for orange and red, and lemon yellow gave much better results.

Public Roads of August, 1925, gives the following definition relative to the physical characteristics of these colors. This code of colors was released July, 1925 under the auspices of the American Standards Association.

"Red. The spectrum of red shall contain both red and orange, but not more than a trace of yellow and no green, blue, or violet. The most desirable hue is entirely free from yellow, which means that the glass does not transmit the yellow light from a sodium flame.

"Yellow. The spectrum of yellow shall contain red, yellow and green, with but little blue and no violet. The most desirable hue is entirely free from blue and might be designated a light amber.

"Green. The spectrum of green shall contain yellow, green, blue and violet, with only a trace of red and orange. The hue is known as "admiralty green" and has a bluish tint when observed by daylight."

In a study made by the American Engineering Council prior to the publication of the 1930 Manual, the following practices were found to prevail:

Three colors were used in eighty-five cities.

Yellow was used after both red and green in seventy-six cities; only after green in eight cities; simultaneously with other colors in eighteen cities.

The duration of the overlap in four cities was less than five seconds, in eight cities, five seconds, in one city, over five seconds.

The two-color scheme was used by twenty-one cities, of which four used an additional red lens.

Five cities simutaneously changed from green to red and from red to green; three had a period of darkness at change of colors; nine had an overlap of red in all directions.

In eighty-eight cities wording was used on lenses as follows:

Green - GO
Red - STOP
Yellow - CAUTION; CHANGE; WALK; WAIT

The Third National Conference on Street and Highway Safety of 1930 made the following recommendation relative to the meaning to be attached to the different colors:

1. Three-Color System, where the colors shall be displayed in the order red, green, yellow.

The meaning of colors in the three-color system shall be interpreted as follows:

(a) Red, means STOP before entering the intersection, and remain standing until green is shown.

(b) Green, means permission to GO, subject to the safety of others, or to the specific directions of a police officer.

(c) Yellow, after green, means STOP before entering the intersection, unless when yellow first appears, the vehicle is so close to the intersection that it cannot be stopped with safety.

(d) Yellow, alone, shall not be used in traffic control systems as a special period for turning vehicles or the movement of pedestrians.

2. Two-Color System. The colors in this system shall be red and green, and the red shall be displayed simultaneously in all directions for the change period.

In the two-color system the colors shall be interpreted as follows:

(a) Red, means STOP before entering the intersection, and vehicles remain standing until green is shown, unless when the red appears the vehicle is so close to the intersection that it cannot be stopped with safety.

(b) Green, means permission to GO, subject to the safety of others or to the specific directions of a police officer.

COLOR SEQUENCES

Color sequences depend upon the various combinations of the change periods with both the green and red lights.

Sequences for Three-Color Signals - Red, Green and Yellow.

Change Period

	Following Green	Following Red
(1)	Yellow	Yellow
(2)	Green-Yellow	Red-Amber
(3)	Yellow	Red
(4)	Green-Yellow	Red

Sequence (1), without the overlap, allows for the greatest simplicity in the control apparatus.

In sequence (2), the combination of the yellow with either red or green, conveys to the driver or pedestrian the information as to the color that is to follow. This is true only during the period of overlapping. Against this arrangement of showing of the green and yellow lights at the same time, there is the objection of giving two different meanings to the same color of light. Green should always mean GO, and according to this arrangement with the yellow, it means CAUTION, and do not enter the intersection. Such contradictory interpretations tend to cause confusion in the mind of the driver, as well as of the pedestrian. This is particularly the case since there is a lack of uniformity in this matter in the different cities, making it extremely difficult for a stranger to conform to local traffic ordinances.

In sequence (3) the yellow light is displayed to moving traffic only, whilst the traffic stopped by the red light does not get the yellow light at all, but goes sharply from a red signal to a green.

Sequence (4) differs from (3) in that there is an overlapping yellow towards the end of the green signal.

Four additional sequences might be considered by having the ringing of a bell accompany the change period following the green light; thus making eight sequences in all.

Sequences for Two-Color Lights - Red and Green

Change Period

	Following Green	Following Red
(1)	All lights out	All lights out
(2)	Red	Red
(3)	Green-red	Red
(4)	Green-red	Red-Green

In sequence (1) the change period is negatively indicated, and therefore, less effective. It is also questionable if traffic may legally be compelled to stand during the "Out" interval.

The objectionable feature to sequence (2) is to be found in the abrupt change from the green to red.

Sequences (3) and (4) are objectionable in having two colors shown simultaneously with different meanings.

As in the case of the three-color arrangements, four other sequences might be possible by accompanying the change from the green to red by the ringing of a bell.

SEQUENCE OF COLORS AS AFFECTING PEDESTRIAN CONTROL

If the traffic signal is to function in an efficient manner, it must provide for the proper and safe movement of the pedestrian as well as of the motor vehicle.

It has been generally recognized that the problem of pedestrian observance of traffic signals is dependent in no small measure upon the sequence and timing of these signals. The clearance intervals for vehicular traffic alone usually give insufficient consideration to pedestrian clearance. Study of the factors entering into this problem has led to the development of a strong demand for an exclusive pedestrian interval. The following methods of providing for such an exclusive pedestrian interval have been classified by E. A. Eames of the Automatic Signal Corporation in a paper delivered at the 1934 Annual Meeting of the Institute of Traffic Engineers.

Massachusetts had incorporated in its state traffic laws the all-red-yellow indication for pedestrian GO, which was preceded by the vehicle clearance interval and followed by all-red for pedestrian clearance. A similar combination of red and yellow for an exclusive pedestrian interval was provided for in New Jersey's standard code for traffic control signals.

Red-Yellow Pedestrian Interval with Three Vehicle Phases

Period	1	2	3	4	5	6	7	8	1
Street A	G	Y	R	R	R	R	RY	R	G
Street B	R	R	G	Y	R	R	RY	R	R
Street C	R	R	R	R	G	Y	RY	R	R

The periods 7-8 are set aside for pedestrian movements. They may appear as part of the fixed-time cycle, or in response to pedestrian actuation.

In Pittsburgh and Philadelphia a double clearance interval was used with a green-yellow, followed by yellow. With this color sequence the vehicle traffic moves on the green-yellow and the usual yellow clearance interval is timed to permit of normal vehicle clearance, and the pedestrian is given sufficient clearance time by the yellow following the green-yellow interval, as set forth in the following table.

Green-Yellow Double Clearance Cycle

Period	1	2	3	4	5	6	1
Street A	G	GY	Y	R	R	R	G
Street B	R	R	R	G	GY	Y	R

Another method of affording the pedestrian sufficient clearance period is to employ an additional indication reading WALK, which appears with the green, but when once extinguished, implies that the pedestrian has no longer sufficient time to cross the street. The weakness of this sequence lies in the fact that in the absence of perfect education, the pedestrian will continue to cross at all times during the showing of the green light.

A STOP-WALKING sign, appearing at the point of the green when it is too late for the pedestrian to enter the street, overcomes the disadvantage of the preceding method.

The green-yellow sequence, as employed in Pittsburgh and Philadelphia, has the advantage of utilizing the standard signal colors and eliminates all auxilliary signals.

In New York City, where the two-color signals are used, another form of double clearance cycle was employed where a dark period followed the green signal, thus serving as a preliminary clearance interval preceding the normal all-red clearance.

New York City Double Clearance Cycle

Period	1	2	3	4	5	6	1
Street A	G	Dark	R	R	R	R	G
Street B	R	R	R	G	Dark	R	R

All of these combinations are possible with fixed-time cycles, and some may incorporate the principle of traffic actuation.

In the case of the traffic actuated signal only, several other methods may be employed in adjusting the color sequence to obtain satisfactory pedestrian control. One of these methods, as used in Massachusetts, provides for two traffic phases, one or both being actuated, and an actuated pedestrian phase appearing immediately after one of these traffic phases, as indicated below.

Double Red-Yellow Pedestrian Actuated Cycle

Period	1	2	3	4	5	6	7	8	1
Street A	G	Y	RY	R	R	R	RY	R	G
Street B	R	R	RY	R	G	Y	RY	R	GR

THREE-COLOR VS. TWO-COLOR SIGNALS

From the data collected by the American Engineering Council for the preparation of the 1930 Manual, it can be seen that prior to that date the use of the three colors red, green and yellow for traffic control signals was more popular than the two-color scheme. This is not surprising, since the idea of using colored lights for traffic signals was borrowed from the railroads, where the three-color standard had already been adopted. However, the data referred to above showed that the cities were divided into two schools of thought on the matter of adopting the three or two-color scheme.

The yellow light was originally used both after the green and the red lights. As a change signal after the red, the yellow claims the advantage of giving the waiting vehicular traffic a signal several seconds before the appearance of the GO signal, which enables the drivers to prepare for an early start, thus producing freer movement of traffic by a more rapid clearance of the intersection. Against this advantage, there is the decided disadvantage resulting from the weakness of human nature, whereby drivers in general become impatient at delays of any sort and follow the urge to "rush" the yellow, thereby creating a potential hazard to the traffic still legitimately clearing the intersection.

One of the principal purposes of the yellow signal is to warn the moving traffic that the GO period is almost at an end and that the STOP signal is about to flash. Drivers who are within fifty to sixty feet of the intersection and driving at a reasonable speed will have ample time to cross the intersection in safety and be clear of the traffic about to cross from the other direction; whereas, the drivers coming on at a greater distance from the crosswalk will have plenty of time to bring their cars under control before the red appears. Such a movement produces a certain degree of confidence and security in the minds of the motorist and the pedestrian alike. It serves as a sort of a safety valve for the traffic in or very near the intersection during the change period.

Buffalo experimented with the two-color light signal during the year 1924, and, after apparently satisfactory results, installed such a light in January, 1925, at one of its busy intersections, having trolley lines in both directions and motor traffic of considerable volume. Further experiments at other intersections, where different conditions prevailed, produced similar results. Practically every signal of the city was later changed to conform to the two-light principle.

W. B. Powell, traffic engineer of Buffalo, N. Y., held that the psychology of this method was correct for the reason that when a driver is approaching an intersection with the knowledge that there is to be no warning, he will proceed with greater caution than in the case when such a warning is used. It was the experience of Buffalo at that time that after the change to the two-color system the number of collisions at intersections thus controlled had decreased considerably.

The New York State Conference of Mayors and other Municipal Officials, in May, 1927, passed the following recommendations of the Committee established to study this question of traffic signals:

1. The only colors which should be used in traffic control signals are red and green.

2. In traffic warning signals, yellow should be used exclusively.

3. The meaning of the colors is as follows:

Red should always mean STOP. It should never be used as a warning or cautionary signal.

Green should mean GO.

In order to avoid confusion, all other uses of red, green or amber lights so located that they may be mistaken for traffic signals, should be discontinued.

The New York Committee felt that this plan provided for greater safety than does the three-light system, for the reason that during the clearance intervals it is not desirable that vehicles shall PROCEED with CAUTION, but that they shall STOP. The use of the red light showing in both directions during this interval provides for an absolute stop and overcomes the tendency on the part of drivers to speed across the intersection prior to an authorized change of traffic movement.

Other things being equal, the two-color scheme was considered as offering the further advantage of a reduction of cost in installation and maintenance.

The Ordinance Committee of the National Conference on Street and Highway Safety, accepting the recommendation of the American Engineering Council, (1930), expressed the preference for the three-color signal light for the reason that at the time of the change from green to red the motorist is called upon to do the impossible, to stop immediately, or if he does not do this, he is passing through the intersection against the red light. And in order not to make this unintentional offender a law breaker, the signal compromises the meaning of the red light. This naturally breeds a contempt of the red light as a STOP signal, which introduces a serious element of danger to the motorist and pedestrian alike.

The use of the three colors red, green and yellow is thus described in the 1934 Manual.

"Red. - While the red lens is illuminated, no pedestrian or driver of a vehicle facing the signal may enter the intersection roadway, provided, however, that if a green lens (for straight through, right, or left turn) is illuminated at the same time, a driver may enter the intersection to make the movement permitted by the arrow.

"Green. - While the green lens is illuminated, it shall mean that the pedestrians and vehicle drivers facing the signal face may proceed into the intersection and pass through, or turn to the right or left, subject to the safety of those who were in the intersection at the time the lens was illuminated, and subject to the exceptional rights of emergency vehicles. Drivers of vehicles making a right or left turn should be required to yield the right of way to pedestrians crossing (or who have started to cross) on a green indication.

"Yellow. - When the yellow lens appears alone, any driver of a vehicle approaching the intersection, or a marked limit line, who can stop with safety before reaching the limit line, must do so. Any driver whose vehicle is so close to the intersection that a stop can not safely be made back of the limit line shall proceed cautiously through the intersection.

"The display of the yellow is recommended after the green only, and not after the red.

"Green and Yellow. - Whenever the green and yellow lenses are illuminated together this shall be a warning to pedestrians that there no longer remains time to leave one sidewalk and reach the opposite side of the roadway before cross traffic will be given its signal to proceed; and that vehicle drivers may continue to enter the intersection while the green and yellow lenses are illuminated together.

"Whenever this combination of green and yellow is used, the combined length of the green-yellow period and of the yellow interval alone which follows it, shall be sufficient for a pedestrian walking at a speed of five feet per second to cross to the opposite sidewalk, or on especially wide streets, to cross to a safety island.

"This green-yellow interval requires a six-interval controller instead of one of four intervals."

The 1934-Manual makes no provision for the alternate two-color traffic control signal as did tne 1930-Manual, but confines its recommendations to the three-lens type for the following reasons.

(a) Its general predominance.

(b) The important functions of the yellow light, which cannot be satisfactorily taken care of with a signal face having only two lenses.

(c) The yellow interval warns approaching traffic and provides necessary time for vehicles in the intersection to clear it.

(d) The yellow light is used in one approved plan of indicating a pedestrian clearance period.

(e) When the signal is not operating as a STOP and GO device, the flashing yellow is valuable as a caution signal

SPECIAL INDICATIONS

Arrow Lenses

Special arrow indications for the following individual movements are permitted by the 1934-Manual: Right turn, left turn, straight through. The special arrow should always be green and should be located below the standard green lens.

Special conditions that may warrant the use of the green arrow for the above purposes are:

(a) At an irregular intersection or one of very heavy traffic where there are few pedestrians and it is desired to permit virtually a continuous flow of certain right turns.

(b) At intersections where there are heavy turning movements, certain of which it is desired to favor during special turning intervals.

(c) At a "T" shaped intersection where it is desired to permit one straight movement to continue uninterruptedly except for a pedestrian interval.

Special arrow indications should never restrict movements during the normal GO interval, and the utility of this indication is dependent upon there being a lane available for the desired movement.

Red and Yellow Combination.

Under exceptional conditions, the 1934-Manual authorized the red-yellow color combination for the purpose of an exclusive pedestrian interval.

Flashing Red (Stop Signal).

The red lens when illuminated by rapid intermittent flashes shall require drivers to come to a complete stop before entering the intersection, and such drivers shall not proceed until it is safe to do so.

Flashing Yellow (Caution Signal).

The yellow lens when illuminated with rapid intermittent flashes shall indicate the presence of a hazard and shall permit drivers to proceed with caution.

COLOR-BLINDNESS

The application of color signals presents a problem for those drivers with a form of defective vision called color-blindness, particularly in the case of the red and green lights. These drivers view both green and red as brown. Therefore, the meaning of these colors has lost its significance for this class of drivers.

According to Dr. Knight Dunlap, there is no separate class of color-blind persons, as this defect ranges from normal to the worst cases. Furthermore, under certain conditions all men may be said to be color-blind in peripheral vision, by observing colors from an angle of fifteen degrees or more. Test for color-blindness, as ordinarily administered, are lacking in effectiveness. In order to catch the worst cases, it is essential that there be prolonged tests for each candidate, and a high degree of skill on the part of the tester, which conditions are difficult to fulfill when a large number of candidates must be examined. Even with the best test, it is impossible to say whether the candidates that just get by are any more secure in their color estimation under traffic conditions then those just excluded.

There are two colors which the color blind person can discriminate as readily as the person of normal vision. These are most easily distinguished in peripheral vision, namely, orange-red and blue-green.

The color-blind driver can be aided by uniformity in the location of the different colors of the signal lights. This uniformity is fairly well established, in placing the red at the most conspicuous place, namely, on the top in the vertical type, and at the outside in the horizontal type of signal. In this manner the driver can distinguish the STOP signal from the GO signal without being obliged to recognize the different colors.

In addition to this arrangement of colors, some signals have words inserted in the lenses. GO and STOP are found on the green and red lenses respectively, and the words CAUTION, CHANGE, WALK, WAIT are sometimes found on the amber lenses. In the survey conducted by the American Engineering Council prior to 1929, eighty-eight cities used such information lenses for their signal lights.

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CHAPTER V

TRAFFIC CONTROL SIGNAL SYSTEMS

HISTORICAL DEVELOPMENT

With motor vehicle traffic continually increasing in the business districts of our larger cities, it soon became apparent that some form of coordination was necessary in order to provide for an orderly and continuous movement of traffic on the more heavily traveled streets.

The Electrical Railway Journal for September 26, 1914, refers to the "Multiple-Unit" traffic control system tried in New York, Fifth Avenue, "where one officer flagged orders to his comrades for some distance down the avenue."

At this period, Cleveland employed electrically-lighted signals controlled from a booth. These signals were also connected with the police and fire alarm circuits to provide for expediting the movement of emergency vehicles.

In 1914, New York experimented with the famous continuous block system; but according to William Phelps Eno, this system proved a complete failure.

In 1919, New York installed traffic towers for the synchronized block system, covering a distance of 1-1/2 miles. This was the first attempt to synchronize traffic in any city. In 1922 seven new bronze towers were installed, similar to those used on the railroads, at a cost of $125,000. From these towers the movements of traffic on Fifth Avenue and cross streets were controlled by flash-lights, telephone and push-button signals, operating between the towers, and to be observed by the traffic officers at the intersection semaphores. The basic idea behind these early installations was the coordination of traffic officers in order that all officers in view of the tower should call for the same directional movement in traffic. They were not intended to give direct indications to the moving traffic which is the primary function of our present traffic control signals.

In 1920 Detroit tried out the block system extending over a distance of a quarter of a mile, and according to Dr. J. W. Inches, a uniform and much speedier movement of traffic resulted. These lights were designed to direct the traffic, and were located at each intersection. In these two respects the Detroit system differed from the New York system, with considerably better results.

Other cities soon followed in adopting similar tower signal systems. In Atlanta, Georgia, traffic signals were suspended over the street intersections, and were connected to a central tower. All of the distant lights were operated simutaneously from this tower.

Los Angeles had a system of combined semaphores and lights installed upon special posts erected at each curb corner. These were operated from a central station so that the traffic was controlled throughout a considerable area. In addition to the signal towers located several blocks apart, there were suspended at every intersection between these towers, signal boxes which were controlled by current from the larger towers, and which showed the same lights, not only to the nearby drivers on the same street who were not able to see the towers, but also to the drivers who were approaching on all cross streets. The ringing of a small alarm bell at each intersection announced the coming change of signals.

The City of Houston, Texas, can lay claim to the installation of the first electrically interlocked traffic control signal system. In February, 1922, signals were installed at nine adjacent intersections connected together electrically and operated automatically in synchronism from a central point.

In 1923 Chicago installed a simultaneous system on Michigan Avenue covering a distance of 2-1/2 miles; and in 1926 put into operation a flexible progressive system of forty-nine signals in the business district and operated from a central control board.

The various steps in signal control methods might be classified as follows.

1. Isolated intersections controlled manually.
2. Isolated intersections controlled automatically with auxiliary hand control.
3. Adjacent intersections synchronously controlled manually.
4. Adjacent intersections synchronously controlled automatically with auxiliary hand control.
5. Adjacent intersections synchronously controlled with provision for operating any intersection or sections of the system as an independent unit.

6. Adjacent intersections synchronously controlled, but timed to give a progressive or wave movement of traffic.

7. Adjacent intersections controlled separately from a dispatching station with flexible control so as to obtain any desired relation in timing of such adjacent intersections.

8. Traffic-actuated control, whereby the GO periods are determined by the demands of the traffic moving in different directions.

9. A combination of fixed-time control signals with traffic-actuated signals.

METHODS OF COORDINATION

On the basis of their method of coordination traffic control signals may be classified into several systems:

1. The simultaneous system - formerly referred to as synchronous, intermittent, separate, rabbit.

2. The alternate system - formerly referred to as progressive, platoon, reverse, split alternate, limited progressive, stagger, wave, reversed synchronized, cascade, ripple, shower.

3. The flexible progressive.

4. Combination of coordinated control with traffic-actuated control.

The Report of the American Engineering Council on Street Traffic Signs, Signals and Markings, Part II, indicated the following forms of control, prevailing in 1929.

	No. of Cities	Per Cent.
Flexible Progressive	29	21.4
Simultaneous	45	32.8
Alternate	13	9.5
Independent installations	50	36.3
Total	137	100.0

Simultaneous System

In the simultaneous system all the signals along the street show the same color in the same direction simultaneously, all intervals change at the same time, and all intersections have equal intervals. The synchronization may be accomplished by means of an interconnected cable with a central control station, or by means of synchronous motors furnished with power from a common source of alternating current.

The pioneer attempts at traffic control where indications were imparted from the early signal towers, such as those of New York and Detroit, produced a movement similar to that obtained in a simultaneous system.

For several years following the first electrically connected automatic signals in the City of Houston, in 1922, the simultaneous system became very popular. After having been put to the test under varying conditions, however, a number of disadvantages soon became apparent.

1. Continuous movement of the vehicles became impossible, since the movement was made up of a succession of starts, stops, and waits.

2. A premium is placed on high speed, resulting in frequent violations of established speed limits, consequent reckless driving and an increase in accident hazards.

3. Although the actual speeds may be high, nevertheless, due to the necessary long stops, the average speed is usually very low.

4. Due to the long waiting periods, drivers become irritated when obliged to stop in the absence of cross traffic, a condition which leads to disobedience of lights by motorists and pedestrians.

5. Its inefficiency lies in the fact that the time allowed for movement on the main street must be the same for all intersections, based upon traffic volume at the most important intersection in the group, which unnecessarily penalizes traffic at the remaining crossings.

6. If street cars are involved, all cars must stop at the same time, which greatly increases the peak power load. On Euclid Avenue, Cleveland, a seventeen per cent increase in power demand was necessary.

Alternate System

According to the 1930-Manual, the alternate traffic control system consists of "adjacent signals or groups of signals showing opposite colors in the same direction at the same time, thus allowing a measure of progressive movement," or "an adaptation of the simultaneous system, obtained by so changing the wiring of adjacent signals or groups of signals that each signal or group as seen from the same direction shows the color having the meaning opposite to that conveyed by the adjacent signal or group."

The 1934-Manual defines an alternate system as "one in which adjacent signals or groups of signals show opposite indications to a given highway at the same time. All signals change their indications at the same time, but instead of all signal faces governing one highway changing from red to green, the first, third and fifth signal faces or groups thus change, while at the same time the second, fourth and sixth signal faces or groups change from green to red."

In the December issue of 1916, American City records E. P. Goodrich's description of the "plattoon" type of signal operation for street traffic control: "What suggested the idea to him was the signal system adopted for elevated trains on the Brooklyn Bridge. Here, signal lights showing alternately red and green were spaced about two hundred feet apart across the bridge and trains could follow each other, without stopping, at a regular speed, much more closely than is possible with the ordinary spacing of train signals. A wave of red lights following immediately behind a train, succeeded by a wave of green lights, suggested the idea as applied to street traffic, as having alternate street blocks filled with steadily moving groups of vehicles with opportunity for cross traffic to move in the intervals between the groups."

The Proceedings of the National Conference on City Planning of 1916 call attention to the fact that John P. Fox proposed a similar plan of control at about the same time as did Mr. Goodrich.

Minneapolis inaugurated an alternate system on December 5, 1925, using the "American Bobby" signal as described in an earlier section of this paper.

In Washington, D. C., a rather extensive coordinated system of traffic control signals was put into operation in the early part of January, 1926. Due to variation in block lengths, two or three adjacent intersections were sometimes combined to show the same color. The results were very gratifying and brought city officials from the larger traffic centers to study the new system. It was claimed that the change was marked by an appreciable decrease in motor vehicle accidents.

Jackson, Michigan, changed its simultaneous system to an alternate system on January 10, 1926. This system covered fifteen busy intersections.

Theoretically, the simultaneous system may be said to represent the spirit of the red light, and the alternate system that of the green light. Specifically, the advantages claimed for the latter might be classified as follows:

1. With favorable conditions of street layout, and spacing and timing of signals, vehicles starting at the beginning of the system on the green light and traveling at the predetermined speed, can continue throughout the entire system without stopping.

2. Speeding is penalized in that the vehicle exceeding the determined speed must stop at the next intersection until the appearance of the green light. With a reduction of speed there naturally follows a reduction of accident hazards.

3. Although the maximum speeds are less than for the simultaneous system, the average over-all speed is greater.

4. Pedestrians will more readily obey the signal when not obliged to wait so long before being permitted to cross the intersection, as is the case with the long cycles ordinarily used for the simultaneous system.

5. The psychological effect upon the driver is a salutary one; he feels that he is getting a break at every signal when he remains within the prescribed speed limits.

The disadvantages of the alternate system are:

1. The STOP and GO periods must of necessity be of the same length; this brings about a certain amount of inefficiency at all except a few intersections where the traffic is evenly distributed.

2. Ideal conditions are found only for blocks of equal length. With unequal block lengths the vehicles must vary their speed to keep in perfect step with the lights. Flexibility is likewise lacking where other conditions call for varied speed, even with equal block lengths.

3. When the average length of blocks is very short, the cycles must be short, or the speed must be reduced to an unreasonably low rate.

4. A grouping of several signals in the case of very short block lengths will raise the speed, but at the same time, will reduce the capacity of the street, because only the vehicles that enter the first intersection of a group during the early part of the green interval can move continously. On a heavily traveled street this condition is cumulative, and the street becomes completely blocked at the peak hours.

5. Street car peak power loads, although less than **for** the simultaneous system, are still a disturbing factor.

Flexible Progressive System

The flexible progressive system, according to the 1930-Manual, is a system where "all signals are so inter-related that the total time period at each intersection is the same, but the period may be varied to meet traffic conditions at each intersection, and in addition the system is designed to provide for the continuous movement of traffic after it has entered the area controlled."

In the 1934-Manual "the flexible progressive system is one using a common cycle length throughout in which, however, the individual signal faces controlling traffic on a given highway show GO indications independently in accordance with a timing schedule designed to permit (as nearly as possible) continuous operation of undelayed groups of vehicles along the highway at a planned rate of speed, and in which the intervals at any signal installation may be independently adjusted to the traffic requirements at that intersection."

Chicago established the flexible progressive system February 8, 1926. The checks made during the first month showed that movements of traffic through the Loop had been speeded up from twenty-five to fifty per cent by these signals alone. Cars that formerly required from eight to twelve minutes to cross the Loop required from five to six minutes after the change.

As referred to previously in this chapter, the Report of the American Engineering Council showed that in 1929, twenty-nine cities were using the flexible progressive system.

Besides the advantages claimed for the alternate system, which hold as well for the flexible progressive system, the latter is capable of a higher degree of flexibility. It makes possible the adjustment of the timing of each signal to the variations in the flow of traffic at each individual intersection thus controlled. Although a constant cycle length throughout the system is required to maintain the proper relationship between the stop and go periods at adjacent corners, it permits modifications of the cycle length depending upon the variations in traffic conditions at different periods of the day. It can further be adjusted to meet the conditions of difference of block lengths better than in any of the other fixed-time systems.

The functional characteristics of this system are well illustrated in the recommendations made by the Central Business District Street Traffic Survey of Pittsburgh - 1927. The following possibilities are available:

1. Having the green light start at any desired second at each corner, and the possibility of promptly and easily changing this setting and re-establishing the same setting in case of trouble.

2. Splitting the total cycle so as to give any desired percentage to either street and of changing this percentage at will.

3. Positive control of the length of the total cycle so as to provide for such conditions as normal and peak periods, rainy and dry weather, and abnormal interruption of traffic.

4. Adopting any amber periods within reasonable limits and of changing the length of the amber periods within reasonable limits.

5. Altering any of these items without affecting any other item excepting, possibly in a minor way, as relates to changes in the amber periods.

6. Providing for optional manual control at certain intersections in emergency cases.

7. Providing central control of all lights in case of fire or other emergency.

8. Control by separate districts or groups.

Several mechanical and electrical methods are employed in order that the total cycle of changes be kept of the same duration for all signals, and the time relations be kept in step.

1. Control of cycle from a central station. Although permitting of the maximum flexibility because of all adjustments being controlled at one point, the cost of such a method is so much higher than for the newer methods that its use has lost in favor.

2. Synchronous motor control requiring the use of induction disc motors at individual intersections, which are kept "in step" by the characteristics of a common power generator supply. This affords the simplest and least expensive method of providing flexible progressive control. Under such an arrangement a common cycle length and correct

coordination will continue until for some reason any of the controllers get out of step. In such cases re-adjustment must be made at these intersections by means of a stop watch.

3. By means of a master controller the controllers at the signalized intersections can be properly supervised, thus affording the following features of flexibility.

(a) In order to meet the varying requirements of traffic the cycle length might be changed at different times of the day.

(b) Provision can be made for several different timing schedules to facilitate the peak flows in certain directions during the different times of the day; for example, the heavy inbound flow in the morning and the heavy outbound flow in the late afternoon.

(c) Flashing operations can be operated from this central controller at any time of emergency.

Kansas City installed such an impulse control system in the early part of 1930, in which were incorporated the following developments:

1. Total time cycle variation was possible from a central control point, thus providing for adjustment of the cycle to meet the traffic flow at different times of the day.

2. Independent initial setting, whereby the control timers at each intersection could be set independently, allowing for any desirable adjustment of the green so as to meet any relationship desired with adjacent intersections which may be necessary to obtain continuous movement.

3. Selective dual reset which permitted two distinct initial settings, operated manually or automatically at the central control point.

4. Automatic control of initial settings were provided for once each cycle. By this device it was impossible for the mechanism to keep out of control for more than one total time cycle consecutively.

5. Yellow sequences could be varied to obtain either the green-yellow overlap or the non-overlap signal sequence.

6. Emergency control was included, whereby the entire system, or a special group of intersections, would show "all red."

7. Remote shut-down of all signals, in all or part of the district could be executed from the central station.

The Broad Street signal system, Philadelphia, extending over a distance of five miles was installed in the latter half of 1931 with these special features:

1. Control apparatus at each intersection, which may be set to permit progressive movement in both directions on Broad Street.

2. A master control located in City Hall, designed for an eventual system of three hundred intersections in ten sections.

3. The total time cycle may be varied at the master controller for the entire system.

4. The percentage of total time at each intersection, allotted to the different signal indications at that intersection, may be varied between wide limits to suit local requirements.

5. It was possible to control signals manually at certain intersections.

6. Any controller which fell out of "step" for any reason could be automatically put back "in step" within two cycles.

7. The existence of trouble at one or more local controllers was indicated at the master control point by the flashing of a light signal on the master control panel.

8. It was possible, from the master control point, to discontinue the operation of any or all sections of the system.

9. It was possible, from the master control, to initiate or discontinue the operations of illuminated traffic signs pertaining to regulation in effect during certain periods of the day, without interferring with the operation of the signal system.

10. It was possible, from the master control point, to operate flashing yellow on Broad Street, and flashing red on the side streets for the entire system or any section of it. This provision was intended to take care of the morning hours from 1:00 A.M. to 6:00 A.M.

11. Operating changes from the central control could be made manually or automatically by means of a master control clock which permitted the setting up of the complete program for one week's time. It was planned to adjust the system to favor the inbound traffic in the morning, and the outbound flow of traffic in the evening.

American City for October, 1932, reports one of the longest signal systems in the country having been completed on Hudson County Boulevard, Bayonne, Jersey City, Union City, West New York, and North Bergen, New Jersey. The system was composed of ninety-five signalized intersections and extended over a distance of fourteen miles. A total of two hundred traffic signals were used in the system.

Michigan Boulevard, Chicago, which carries more than 60,000 motor vehicles every twenty-four hours, had been operating under a simultaneous system for several years. In September of 1934 this system was replaced by a flexible progressive control which included thirty-three intersections, and extended over a distance of two and nine-tenths miles.

The characteristic features of this system are:

1. Special WALK indications for pedestrians. Although these are not exclusive pedestrian intervals, the pedestrians are notified by the darkening of the WALK lens that there is no longer sufficient time left to cross the street.

2. At many intersections the timing for moving traffic in one direction is independent of that moving in the other direction.

3. The amber light, which overlaps both red and green, is of different lengths for the two colors, the amber following the red being shorter than for that following the green. This measure was adopted to provide against the "jumping" of the amber light.

4. At certain intersections the showing of a green arrow during the green light period serves as a signal for left turns from the avenue.

5. Flashing green indicates to the operators of vehicles the proper speed at which to travel, thereby creating the correct widths of "through" bands of moving vehicles.

6. A three-dial feature allows three independent settings of all periods at each intersection, thereby providing the maximum efficiency during the morning and late afternoon peak hours, and for average conditions.

The average speed for this new system has been determined at about twenty-four miles per hour.

The efficiency of any flexible progressive control system may be seriously affected by such factors as very short blocks, especially where reasonably high speeds are possible; a mixed composition of traffic of different speeds; complicated intersections requiring three GO intervals; and by heavy turning movements.

The general tendency within recent years has been very strongly in favor of the flexible progressive system when fixed-time signals are employed. It is claimed that this system results in considerably higher average speed values; yet, as to whether a greater per hour capacity results under conditions where there is approximate saturation, is a debatable question. The proper answer to this question is only possible when sufficient factual data are obtained on the operation of the various systems, in order to determine the operating characterisitcs of these systems with respect to over-all average speed, delay, cross traffic conditions, pedestrian observance, accidents, and public reaction.

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CHAPTER VI

TIMING OF TRAFFIC CONTROL SIGNALS

In the earlier forms of officer control of street traffic, changes in vehicular movement were very largely influenced by the human equation of the individual in charge. With the advent of the automatic signal, and particularly the sutomatic signal systems, it soon became apparent that the efficiency with which the streets were to be used under electrical traffic control, depended to a very considerable extent upon the accuracy with which the intersection time was determined and proportioned.

Definitions for the terms "Cycle" and "Interval" as used in this discussion are those found in the 1934-Manual.

"Cycle, is the number of seconds necessary in any signal installation to provide once for all of the intervals required to start and stop each movement of traffic at the intersection.

"Interval, is that part of the cycle in seconds during which the traffic indication of any particular signal face does not change."

THE LENGTH OF CYCLE IN SIGNAL TIMING

During the period from 1922 to 1926 when automatic traffic signal development was still in its primitive form, the use of the long cycle was the prevailing practice. This might be termed the period of the "Long Cycle." Traffic was viewed with the eye of the individual traffic officer who, seeing a long line of vehicles on one of the streets, was guided by the preoccupation of getting that one line past his intersection as soon as possible, but at the same time failing to visualize the cross streams held up by such a procedure.

With simultaneous control it was deemed necessary to have a comparatively long cycle to permit travel for a reasonably long distance; otherwise much valuable time would be lost in stopping and starting.

New York had been held up as the proponent of the long cycle, with frequent complaints that traffic delays and consequent congestion were characteristic of the manner in which New York handled its street traffic. With an undue preference given to the north and south traffic, the crosstown travel was frequently subjected to a series of long and annoying stops.

The Electrical Journal of July 30, 1927, listed the following cycles as used in the respective cities. On Fifth Avenue, New York City, a cycle of one hundred and eighty seconds was in use, giving one hundred and twenty seconds for through traffic and sixty seconds for cross movement. Atlantic City used a cycle of two hundred and forty seconds with intervals of one hundred and fifty and ninety seconds for through and cross traffic, respectively.

Regulation of traffic by means of signal control lights had progressed so rapidly in the period following 1926 that keen interest was manifested in questions that were unheard of a few years previously. In this category was the matter of the proper duration of the cycle of operation. Although great diversity existed in the timing of the signal then in use, there was a decided trend favoring the short cycle. It was felt that the survival of the long cycle practice was one result of making traffic control a police matter instead of an engineering operation.

In connection with the Chicago Survey conducted in 1925-26, it was discovered that in some cities the majority of signals in outlying districts were operating on cycles below fifty seconds. In 1926, Los Angeles was changing its control system sixteen times a day, in order to take care of the traffic variation. In the same year, Detroit varied its cycle from sixty to seventy-two seconds covering normal, peak flow, and traffic on days of rain and snow. When signals were first installed in Cincinnati, they were operated on the simultaneous principle with a ninety-second cycle. When later changed to the alternate plan with the same cycle length, little improvement resulted. With a reduction of the cycle to fifty seconds, results were most satisfactory for both automobile and street car traffic.

When the system for the Chicago Loop was planned in 1926 provision was made for a ninety-second cycle. Practice soon proved that traffic movement was more facilitated by varying this from sixty seconds when travel was light, to eighty seconds in the rush hours.

Engineering News-Record of August 14, 1930 carried the announcement that New York had finally adopted a shorter cycle for its traffic control signals, with the result that on many congested streets the traffic was moving faster. New York thus fell in line with the more progressive cities that were benefiting by the greater efficiency of the short traffic intervals and the progressive lighting systems.

In the summer of 1932, the Bureau of Public Roads conducted an investigation at the intersection of Constitution Avenue and 17th Street, Washington, D. C., with the view of determining the relative effectiveness of various types of control, including traffic movement under no control, officer control, vehicle-actuated control, and fixed-time control. The report of this study was published in Public Roads of February, 1934.

In the case of fixed-time control, seventeen different cycle combinations were used, with intervals varying from fifteen to seventy-four seconds; and the cycle lengths varied from thirty to one hundred and twenty seconds.

Two conclusions of this study bearing upon cycle lengths were indicated.

(a) "The fastest movement under fixed-time control was attained with a setting of fifteen seconds on each street; this was the smallest cycle used. Although this setting was the most satisfactory for the moderately heavy traffic that prevailed at the intersection it cannot be concluded that such would be the case under conditions of very heavy traffic.

(b) "At that intersection it was deemed more important that the cycle be kept short than that the time within the cycle be correctly proportioned. This was not to be taken as a general conclusion, for with congested traffic it is obvious that correct proportioning is quite effective."

In September, 1934, Michigan Avenue, Chicago, which ranks among the leading traffic arteries in the world, changed from the simultaneous to the flexible progressive system; and in so doing reduced the cycle length from one hundred and forty to eighty seconds. The average speed of nineteen m.p.h. for light traffic under the old system was raised to twenty-four m.p.h., and for heavy traffic from six to twelve m.p.h.

The 1930-Manual gave the following recommendation for cycle lengths.

"The length of the cycle should be determined by careful consideration of all the factors involved in the regulation, such as:

(a) "A total period of forty to eighty seconds should be used for the control of ordinary traffic.

(b) "Changes in total periods for rush hours may be advisable. Consequently, timers (or controllers) should have flexibility of adjustment through a wide variation of time periods."

The Massachusetts Code of 1931 gives specific recommendations for the timing of traffic control signals.

(a) Intersections with three or four entering ways:
Without pedestrians - a period of sixty seconds
With pedestrians - a period of eighty seconds

(b) Intersections with five entering ways:
Without pedestrians - a period of eighty seconds
With pedestrians - a period of one hundred seconds

(c) Special intersections with unusual conditions
a period of one hundred and twenty seconds onds

The 1934-Manual recommends that "The cycle shall be as short as will accommodate the necessary movement.

"For city conditions a cycle length of from thirty to fifty seconds is generally found to be satisfactory for the usual intersection. For rural intersections, it may be desirable to use somewhat longer cycles, giving extra time to the main highway."

This Manual enumerates the various elements that influence the proportioning of the signal period. These are:

(a) Time required by traffic entering the intersection.

(b) Relative number of lanes in each direction.

(c) Proportion of slow moving vehicles.

(d) Critical lanes, that is, those requiring greater time to discharge the traffic load.

Specifically, the 1934-Manual adds, "Recent experiments show that excellent efficiency can be attained under certain off-peak conditions with fifteen-second intervals closely approaching the performance of traffic actuation, but, in general, no vehicle GO interval should be less than ten seconds. Where the pedestrian clearance is used, not less than five seconds should be provided for the interval for which it is intended that pedestrians shall start to cross. If necessary, enough more than five seconds should be provided to permit the waiting pedestrian groups to enter the roadway."

In Transactions of the National Safety Council, 1929, pages 109-128, T. M. Matson, Traffic Engineer of Philadelphia, brings out certain relationships as they are influenced by different cycle lengths, in the following equations and accompanying diagrams.

Figure 8 illustrates the delay caused at intersections, expressing this delay as a function of the total cycle in seconds, the number of vehicles delayed in each cycle, the speed of vehicles in m.p.h., and the rate of flow of vehicles per hour. In general, it is seen from the diagram that shorter cycles result in time savings, and that the increment in total delay for any cycle becomes proportionately heavy for high densities.

The equation $$E = \frac{C - 2P}{C}$$

shows the effect of the clearance periods (P) on the useful time that a signal affords for traffic flow for different cycle lengths, (C). Figure 9 gives the variation in efficiency for clearance periods of 3, 5, 7 and 10 seconds for different cycle lengths.

The equation $$V = \frac{1.36 \times B}{C}$$

shows that for the alternate system continuous speed of traffic flow (V) is a function of the block length (B), and the cycle length (C). Figure 10 shows this relation graphically. Very short blocks tend to complicate the signal timing problem. In order to maintain a reasonable speed in such cases the multiple-block movement may have to be employed, which always causes a reduction of at least fifty per cent of the efficiency of the intersection to handle the traffic.

OBJECTIVES IN SIGNAL TIMING

In determining the signal timing a number of objectives should be kept in view.

1. To prevent or reduce to a minimum the accumulation of traffic in any block or series of blocks.

2. Timing to be in accordance with the relative volume of traffic flow per lane at each intersection.

3. To permit, as far as possible, the flow of traffic at the speed which is normal for the area traversed, with due regard for the safety of all the elements using the roadway surface.

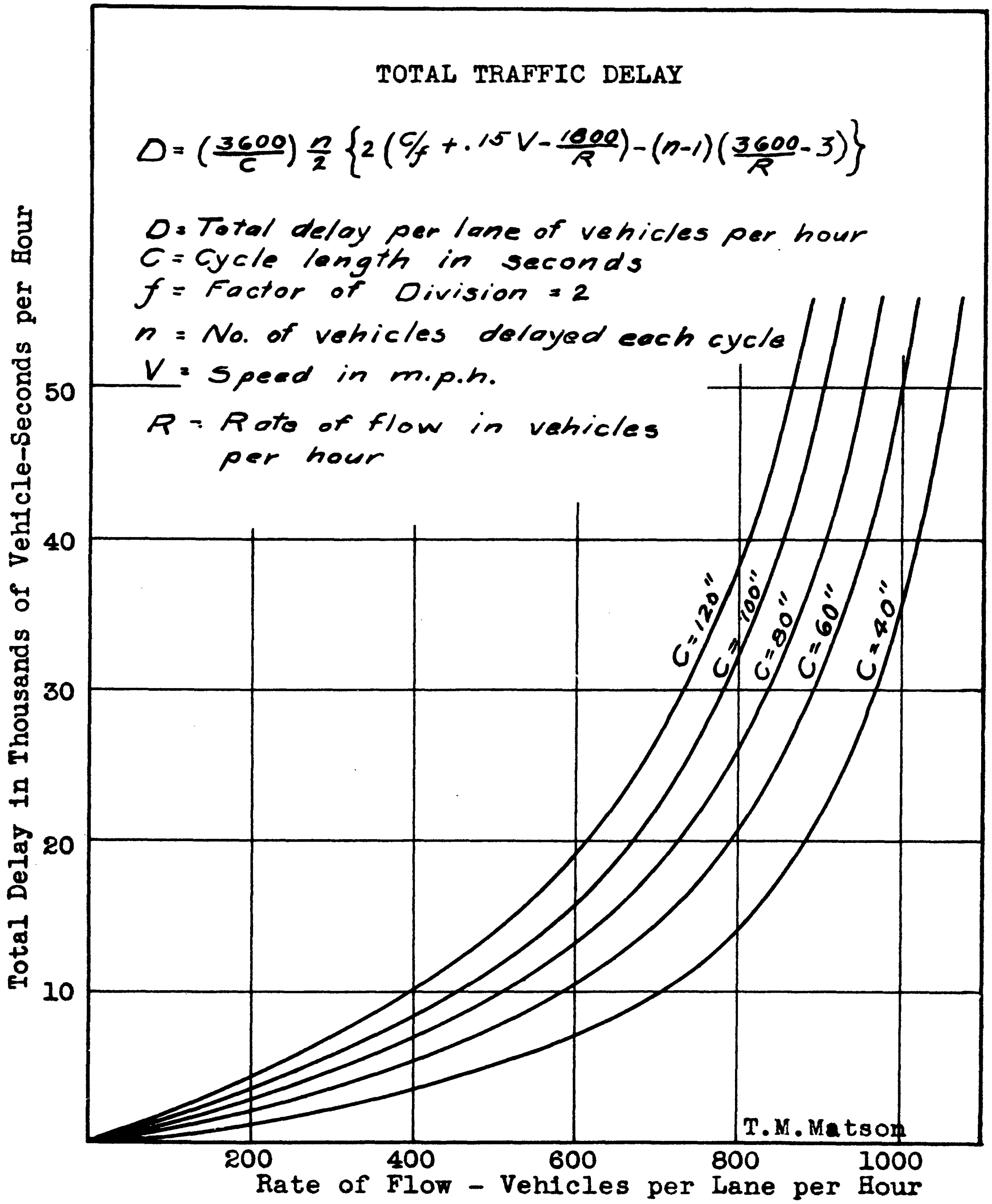

TOTAL TRAFFIC DELAY
D = (3600/C) n/2 {2 (C/f + .15 V - 1800/R) - (n-1)(3600/R - 3)}
D = Total delay per lane of vehicles per hour
C = Cycle length in seconds
f = Factor of Division = 2
n = No. of vehicles delayed each cycle
V = Speed in m.p.h.
R = Rate of flow in vehicles per hour
C=120"
C=100"
C=80"
C=60"
C=40"
Total Delay in Thousands of Vehicle-Seconds per Hour
10
20
30
40
50
200
400
600
800
1000
Rate of Flow - Vehicles per Lane per Hour
T.M.Matson

Fig. 8

TIME EFFICIENCY

$$E = \frac{C - 2P}{C}$$

C = Cycle Length
P = Clearance Period

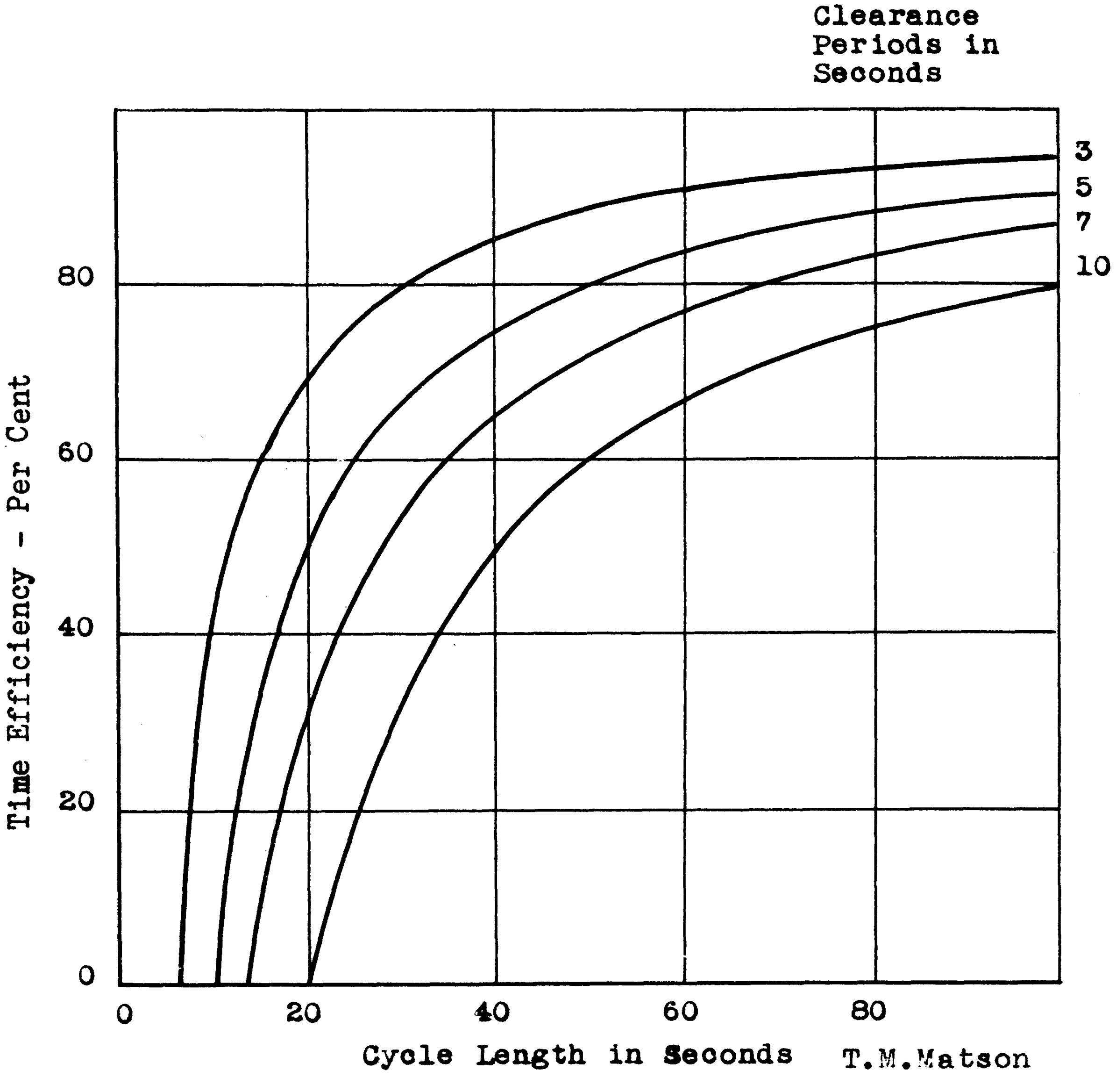


Fig. 9

VARIATION IN TRAFFIC SPEED

$$V = \frac{1.36\ B}{C}$$

B = Block Length in Feet
C = Cycle Length in Seconds

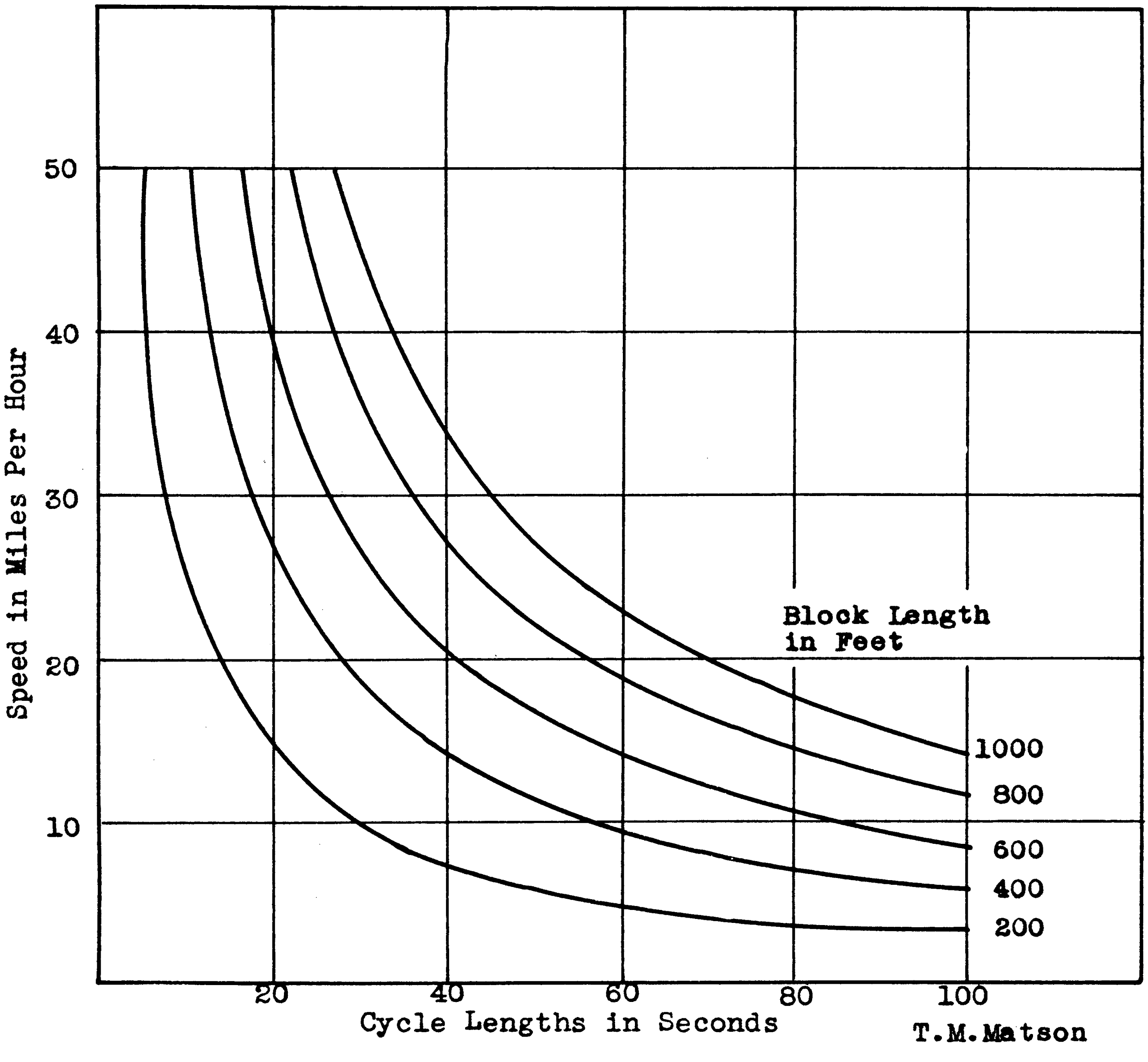


Fig. 10

4. Timing to vary with the traffic speed and volume throughout the day.

5. To prevent or reduce to a minimum the simultaneous flow of conflicting streams of traffic for both vehicular and vehicular with pedestrian movements.

6. The minimum cycle length that will probably handle the traffic at the critical point of the signal run and produce a reasonable speed along the street,'which should vary for the central, intermediate and outer high speed zones.

7. The widest possible time band for through non-stop movement, which ought to be around forty per cent of the cycle or eighty per cent of the GO time at the critical intersection.

8. Cross-town runs interlocked with the main runs to produce the same results for heavy cross-town streets.

9. All surplus cross time, not needed to be thrown to the main street and to accommodate delayed traffic, cars, or buses, on the main streets and aid cut-in traffic from the side streets to get back into the procession without stopping.

10. A minimum pedestrian interval based on four and five-tenths feet per second.

TIME-SPACE DIAGRAMS

The proportioning of the cycle at signalized intersections forming a part of a continous signal system is much facilitated by the use of the graphical method. This consists in the construction of the time-space chart with the time in seconds represented on the horizontal axis, and the distance in feet along the main street to be signalized on the vertical axis.

The cross streets are laid off to a convenient scale along the vertical axis and projected across the chart in a horizontal direction. The center line is usually sufficient, except in the case of very wide streets, when the entire street width may be required.

The diagonal lines indicate the speed at which the vehicles travel; the space between two adjacent parallel lines in the same interval represents a "time-band" of vehicles as they move along the main street during the GO period.

Simultaneous System

Figure 11 is a time-distance chart for a simultaneous system of traffic control signals. For simplicity, the blocks are taken as of uniform length. With the scales adopted for the horizontal and vertical axes, the diagonals are drawn for any given speed by using the following relation.

$$\text{Speed (in ft/sec)} = \frac{\text{distance (in feet)}}{\text{time (in seconds)}}$$

In Figure 11, a speed of twenty m.p.h. is chosen. Taking a distance of 3600 feet along the main street, the time required to travel this distance is found by substituting in the above equation.

$$20 \times \frac{5280}{3600} = \frac{3600}{t}$$

$$t = \frac{3600}{20 \times 1.467} = 122 \text{ seconds.}$$

Pass horizontally from 7th Street - 3600 feet from 1st Street-and then vertically from the abscissa at one hundred and twenty-two seconds. Draw a line from this point on to the zero point of the diagram, and this diagonal represents a vehicle travelling at twenty m.p.h.

Assuming the traffic to move at the chosen speed of twenty m.p.h., the cars represented by the time-band A-B, about twenty seconds in this case, would be able to travel as far as 7th Street, a distance of 3600 feet, before being stopped by a red light; here they would be delayed for periods ranging from forty to fifty-four seconds before the green light again showed in their favor, after which they could proceed to the end of the system at 11th Street before being confronted by a red light. The groups of cars represented by the bands B-C, C-D, etc., would be delayed twice in travelling through the signal system for the total distance of 6,600 feet.

As one of the natural consequences of this system, there is a strong tendency to travel at speeds in excess of that which is reasonable and proper. The band X-Y, including a group of vehicles leaving for a period of about twenty seconds after the showing of the green at 1st Street, and travelling at a speed of forty m.p.h., will be able to pass through the entire distance of 6,000 feet without a single delay. Such speeds were often to be seen on some of the

SIMULTANEOUS SYSTEM

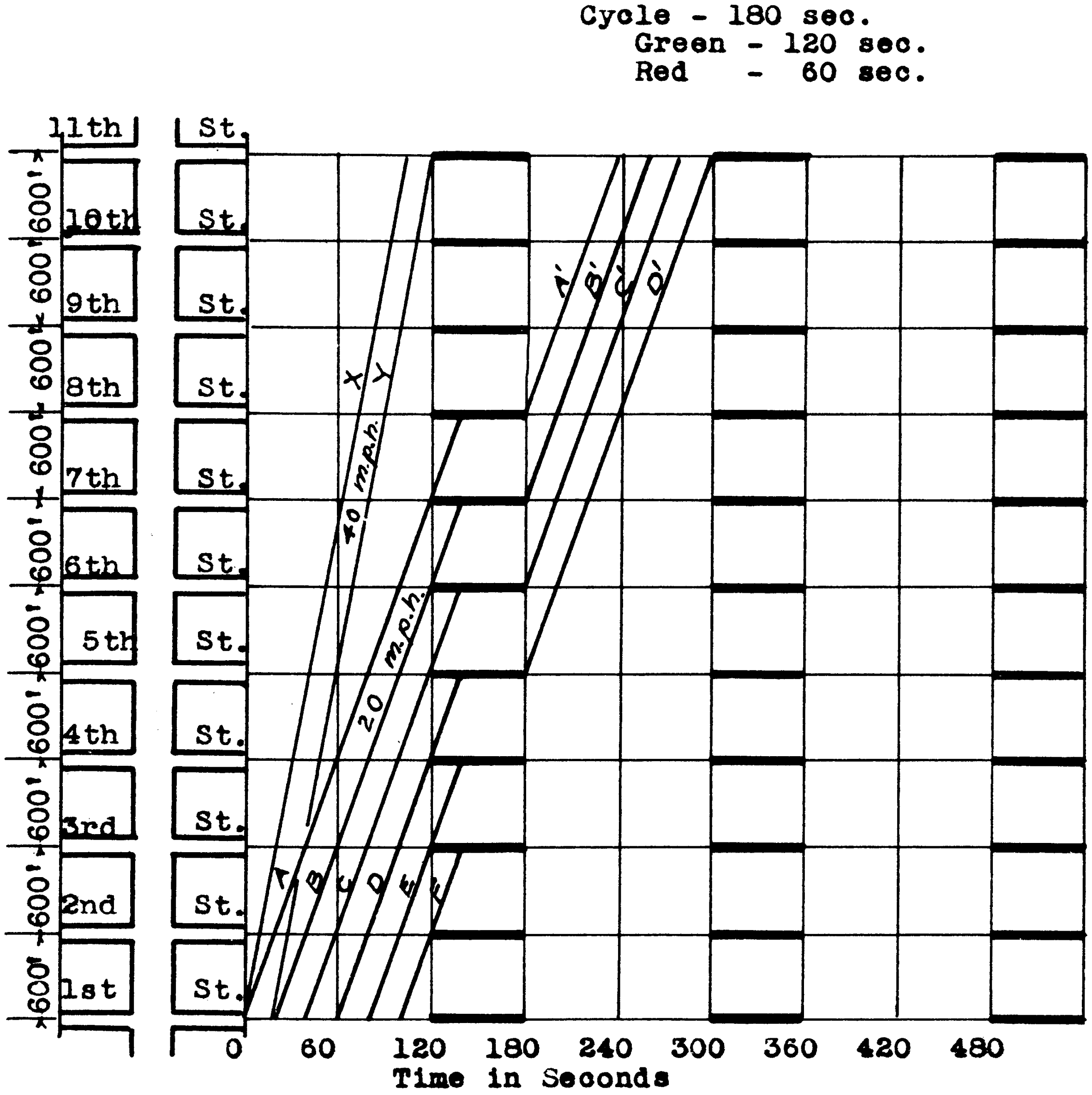


Fig. 11

heavily travelled boulevards with signals operating under the simultaneous system.

In Figure 12, another chart for a simultaneous system, T. M. Matson shows that progressive movement is theoretically possible under certain conditions.

In the equation $V_1 = \frac{D}{c/2}$, which represents a maximum speed for the alternate system of a similar layout, B is the speed in feet per second, D is the block length in feet, and C, the cycle length in seconds. Taking this as unity, and with equal total cycles, progressive movement for a simultaneous system will result at speeds expressed by the even reciprocals of that speed V_1. For example, $V_2 = V_1/2$, $V_3 = V_1/4$, etc. These values are shown by the different diagonals on the chart.

In practice such a condition is not obtainable, except in the case of street cars and other slow moving vehicles.

Alternate System

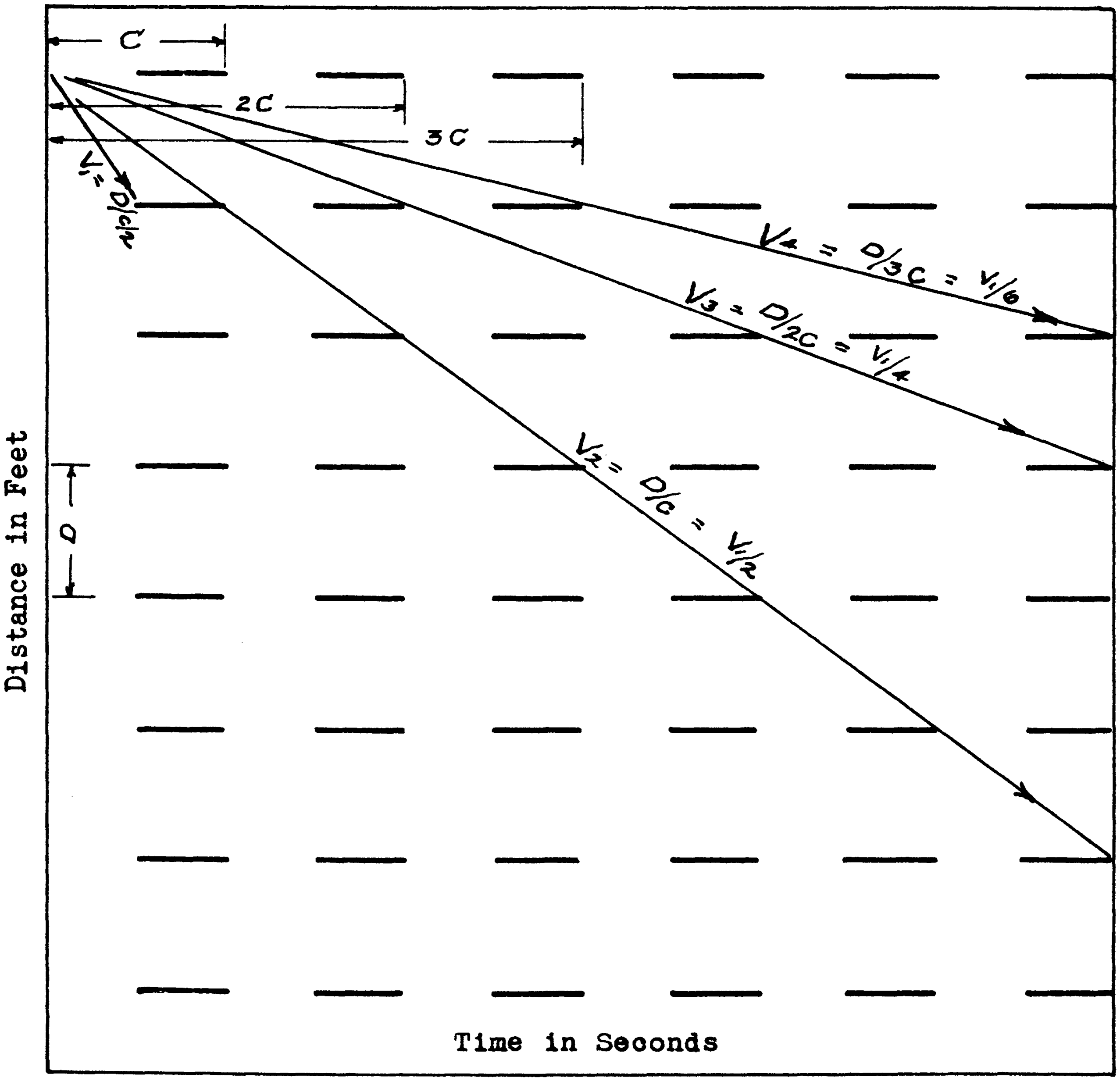
A timing chart for the alternate system is shown in Figure 13. In this system successive intersections show different colors, with an equal division of the cycle which is constant throughout for all intersections. Continuous flow becomes possible as long as the traffic maintains the speed for which the system is designed. This system is particularly applicable to streets where the blocks are of uniform length, and the traffic uniformly distributed over the cross streets.

In Figure 13, a cycle length of fifty seconds was assumed, and for the street layout in question the speed of sixteen and four-tenths m.p.h. is computed. The diagonals represent the traffic flow in both directions. A clearance period of four seconds was chosen preceding the red only. This gave an effective GO interval of twenty-five seconds, and a STOP interval of twenty-one seconds.

Analysis of Figure 14, another timing chart for the alternate system, shows that progressive movement may also be obtained in such a design at speeds expressed as the odd reciprocals of the highest speed, i.e., if the highest speed for which the signal system is designed is taken as unity, then progressive movement may take place at speeds of 1/3, 1/5, 1/7, etc., of this highest speed.

SIMULTANEOUS SYSTEM

C - Cycle Length in Seconds
D - Block Length in Feet
V - Speed in Feet per Second



T.M.Matson

Fig. 12

This phase of signal design (similar to that referred to in Figure 9), is found applicable to slow moving vehicles such as street cars, when by reason of their importance it is necessary to take this form of transportation into consideration in designing the traffic signal system.

Multiple-Block System

In the case of very short blocks, the simple alternate system results in one of two unsatisfactory conditions. To maintain a normal speed would give a cycle that is entirely too short; and to choose a reasonable cycle length, the speed would not be suitable for normal traffic, resulting in the delay of vehicles at almost every intersection, which would quite naturally encourage a general disregard for signal control.

Figure 15, is a solution for a street with short blocks. The signal lights, instead of alternating at every other intersection, do so at every second intersection; thus giving a "multiple-block" movement. The cycle division is the same for all intersections. In the example chosen, the blocks have a uniform length of four hundred feet; the cycle is sixty seconds, giving a speed of eighteen and two-tenths m.p.h. The cycle distribution on the main thoroughfare is: Green, thirty seconds; red, twenty-five seconds; and yellow, five seconds. As is readily observed from the chart, the capacity of the main route is reduced to one-half, which is an objectionable feature of this method of design. Such a condition might be satisfactory for a period of the day when the traffic flow is rather light, and when it is desirable to keep the traffic moving progressively at a high speed.

Flexible Progressive System

Where there is a considerable variation in the length of blocks along the thoroughfare to be signaled, and in the portion of the cycle to be allotted to the red and green intervals, none of the methods thus far considered give satisfactory timing at the different intersections. Such conditions can be provided for in the flexible progressive system, where the cycle length remains constant for all intersections, but the division of the cycle into STOP and GO intervals varies according to the traffic flow in the different directions.

Figure 16, is a time-distance chart for a flexible progressive system. With a cycle of sixty seconds chosen, the green and red intervals most suitable for the respective

ALTERNATE SYSTEM

Cycle - 50 sec.
Green - 25 sec.
Red - 21 "
Yellow - 4 "

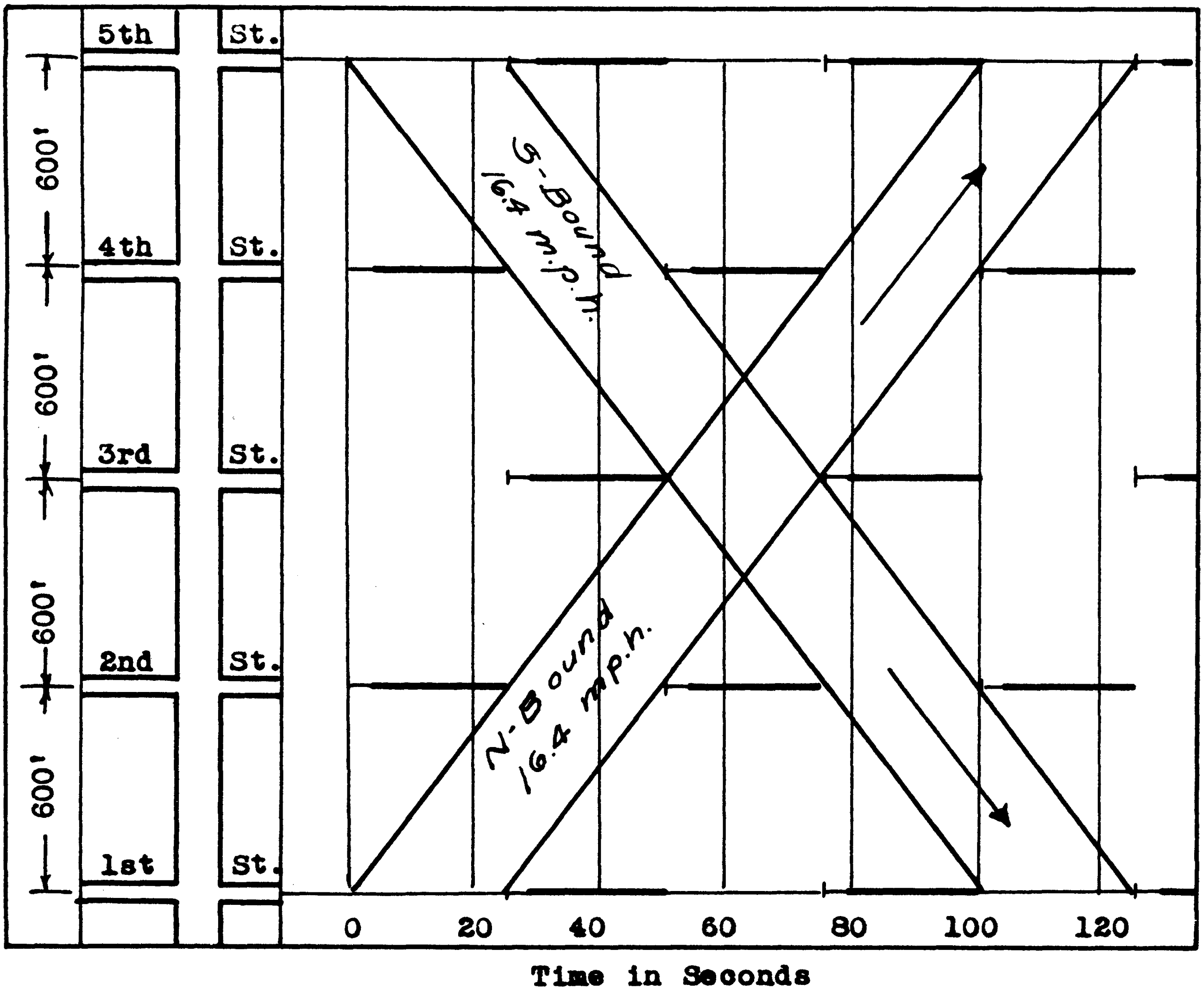


Fig. 13

ALTERNATE SYSTEM

C - Cycle Length in Seconds
D - Block Length in Feet
V - Speed in Feet per Second

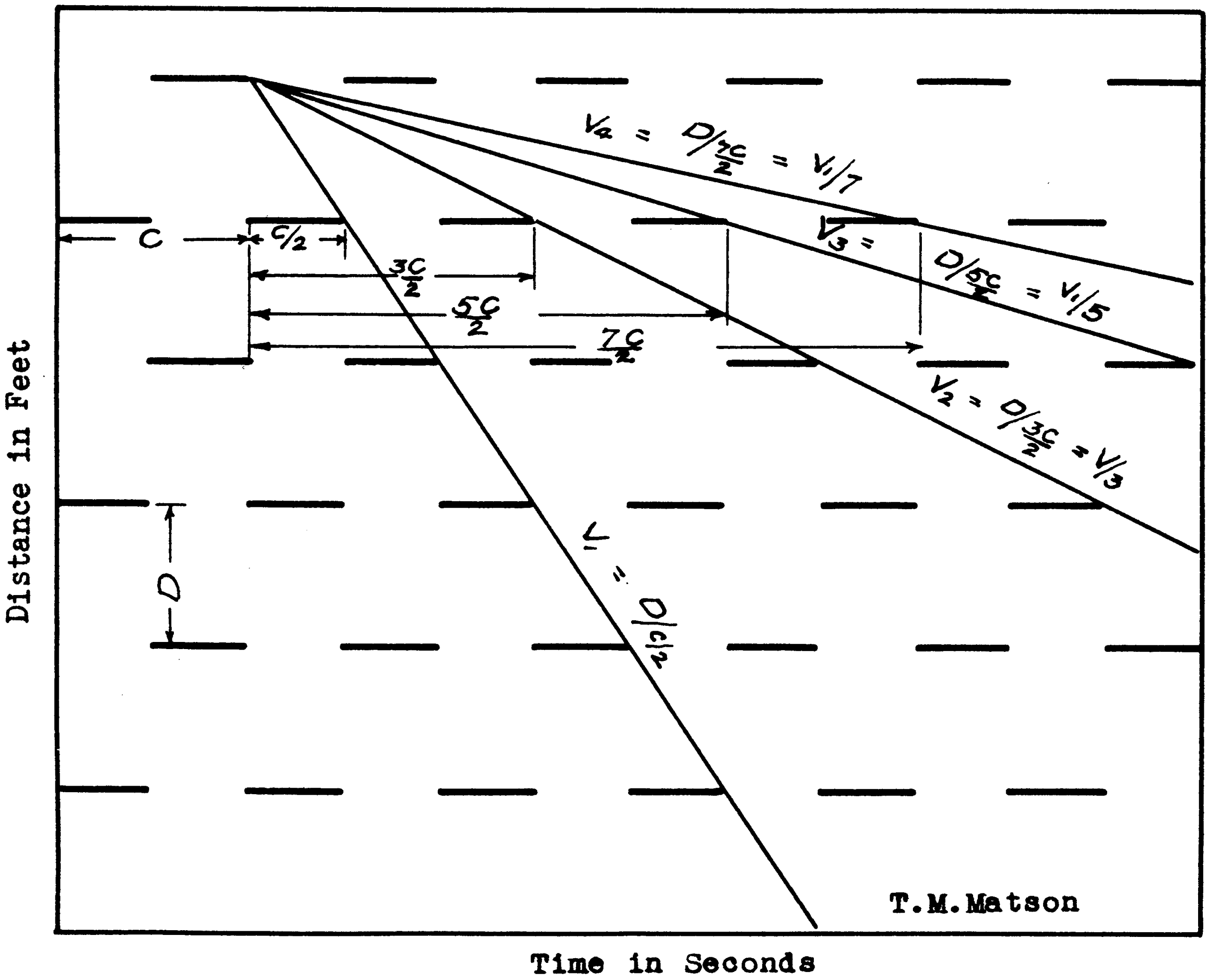


Fig. 14

intersections are determined. In figure 16 the north-bound traffic, with a time-band of about twenty seconds, can travel through the system uninterruptedly at a speed of twenty m.p. h.; whereas, the south-bound traffic, with a time-band of twenty seconds, is reduced to a speed of eighteen and six-tenths m.p.h.

At the Third Annual Meeting of the Institute of Traffic Engineers held in 1932, K. W. Mackall, Engineer of Cross-Hinds Company, developed the following method for the construction of a time-space graph for the flexible progressive system, as shown in Figure 17.

Following the usual practice, the main thoroughfare and the cross street distribution are laid out along the vertical axis, and the time in seconds along the horizontal axis. The speed can be determined by observation of the prevailing speeds at the locality in question, or it may be taken as the legal speed prescribed by the local ordinance. A speed of twenty m.p.h. was chosen for this example. The cycle length is determined by the various methods discussed in previous portions of this paper, or by using one of the several formulas developed for this purpose. A sixty-second cycle was here used. The cycle distribution is obtained by observation of the relative volumes of traffic to be provided for in the different directions.

The minimum green interval determines the maximum time-band of travel as indicated by the lines A-B, C-D, E-F, G-H, for both directions. The intersection of these lines forms a parallelogram, the vertical diagonal of which when prolonged gives the line O-O'. "For the best average progression in both directions, the line O-O' will then bisect either a green interval or a red interval on each street. It is then a simple matter to lay out the green and red intervals for each street. The question as to whether the line should bisect a red or green interval may be determined quite readily by inspection." It is the use of the line of symmetry that characterizes this method of cycle division.

Adjustments of the lines determining the time-bands may be necessary in order that they clear the red intervals entirely. This has been done in the present example by the construction of parallel diagonals shown by the heavy lines.

The tabulations to the right of the graph give in summary form the cycle division into green, red and yellow; the offsets in seconds for the beginning of the cycle from a chosen line; the offset dial in per cent, obtained by

MULTIPLE BLOCK SYSTEM

Cycle - 60 sec.
Green - 30 sec.
Red - 30 sec.

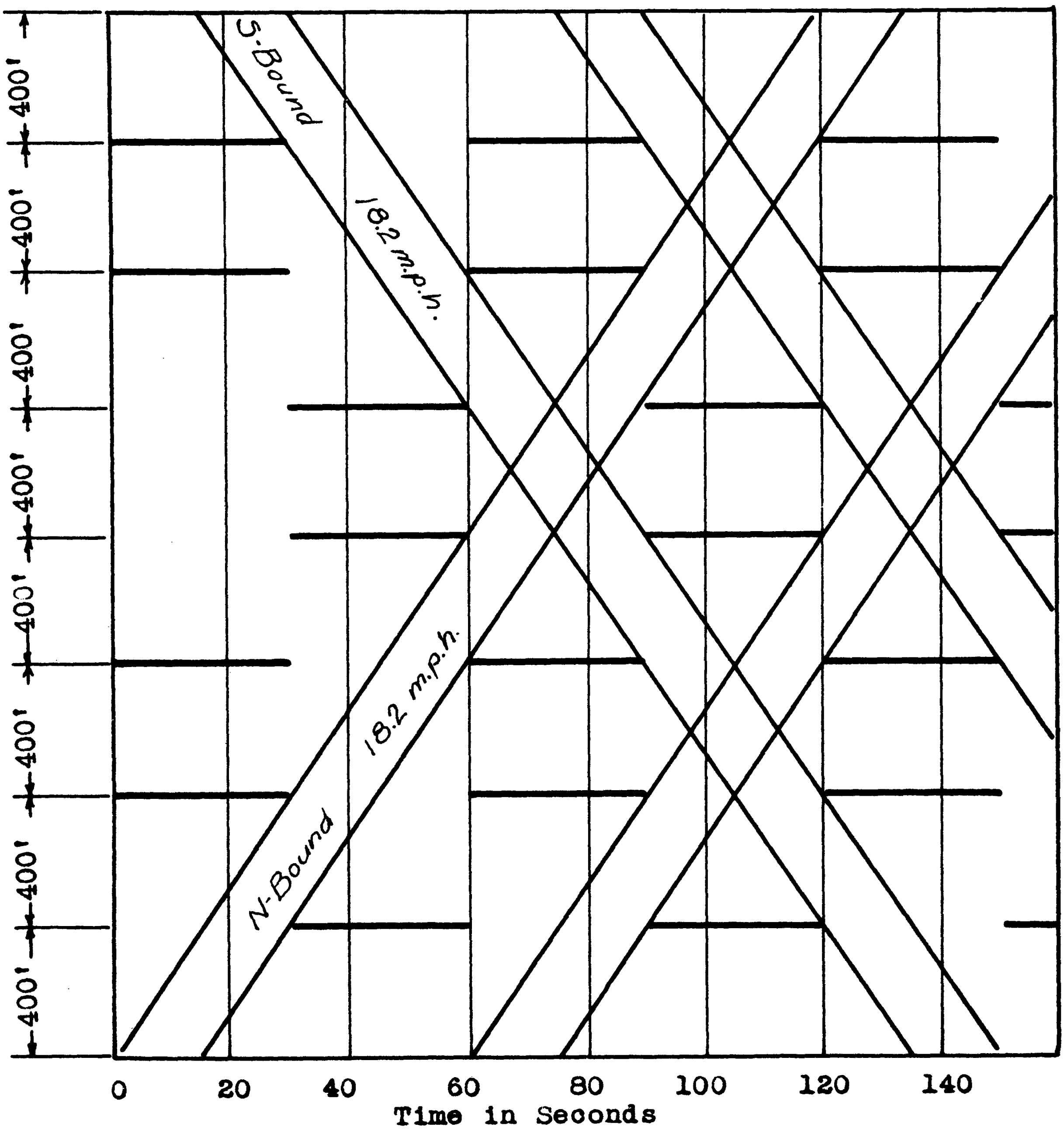


Fig. 15

FLEXIBLE PROGRESSIVE CONTROL

Cycle - 60 sec.

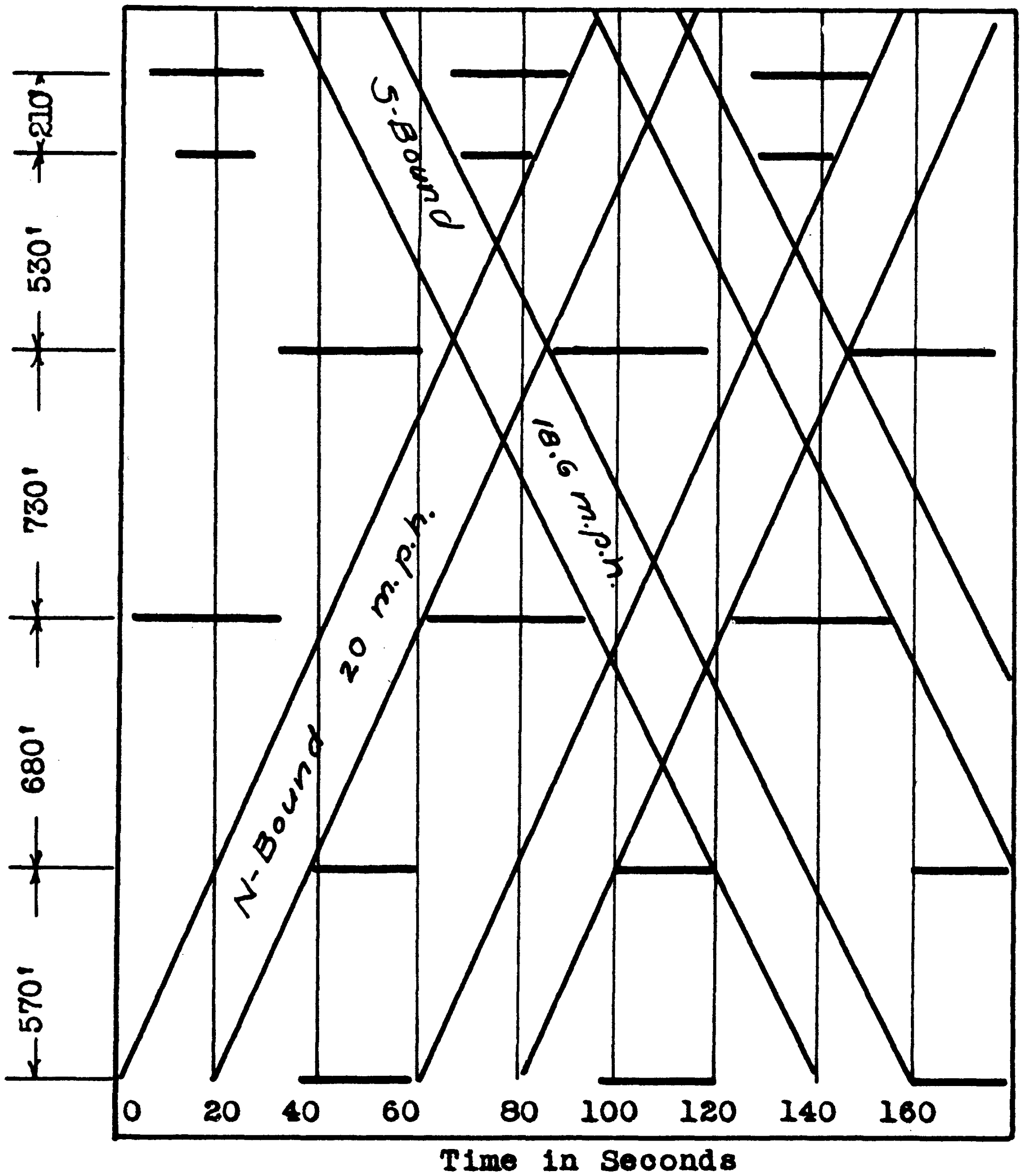
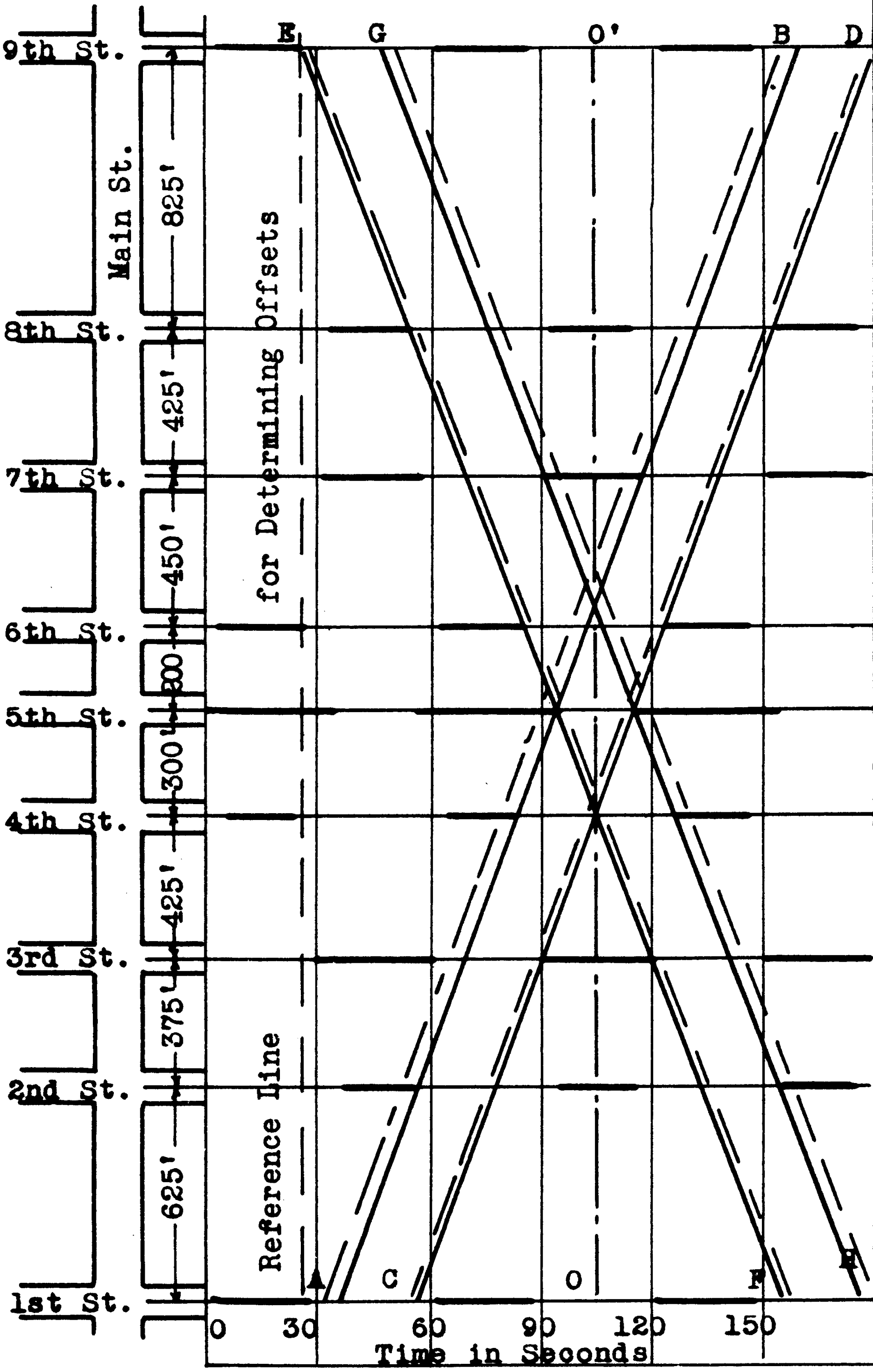


Fig. 16

FLEXIBLE PROGRESSIVE CONTROL

Cycle - 60 sec.



Split Dial %	Time in Sec. Main Green	Main Yellow	Cross Green	Cross Yellow	Offsets in Seconds	Offset Dial %
60	36	3	18	3	0	0
65	33	3	15	3	28	46
55	35	3	21	3	32	54
65	39	3	15	3	58	96
40	24	3	30	3	6	10
70	42	3	12	3	57	94
50	30	3	24	3	33	54
75	45	3	9	3	25	42
55	33	3	21	3	2	4

K.W.Mackall

Fig. 17

dividing the offset in seconds by the total cycle length; and the split dial in per cent, obtained by dividing the green interval by the cycle length.

Traffic flow may be unbalanced during a certain period of the day, with a very heavy flow in one direction. Under such conditions it may be deemed desirable to favor these heavy traffic movements. This can be accomplished in two ways.

Figure 18, shows a time-distance chart providing for such unbalanced traffic. The cycle is chosen as sixty seconds; green, thirty seconds; red, five seconds; and yellow five seconds, after the green only. A maximum time-band of thirty seconds is given to the direction of heavy traffic. With this arrangement, however, the vehicles travelling in the opposite direction are penalized by being forced to travel at a speed of approximately six m.p.h.

In Figure 19, the same street layout and the same cycle length and cycle distribution are maintained as in the preceding example. By allowing a speed of approximately seventeen m.p.h. for the light traffic flow, the vehicles in this class are not subjected to the same penalty as in the preceding case.

UNBALANCED CONTROL

FAVORING NORTH-BOUND TRAFFIC

Cycle - 60 sec.

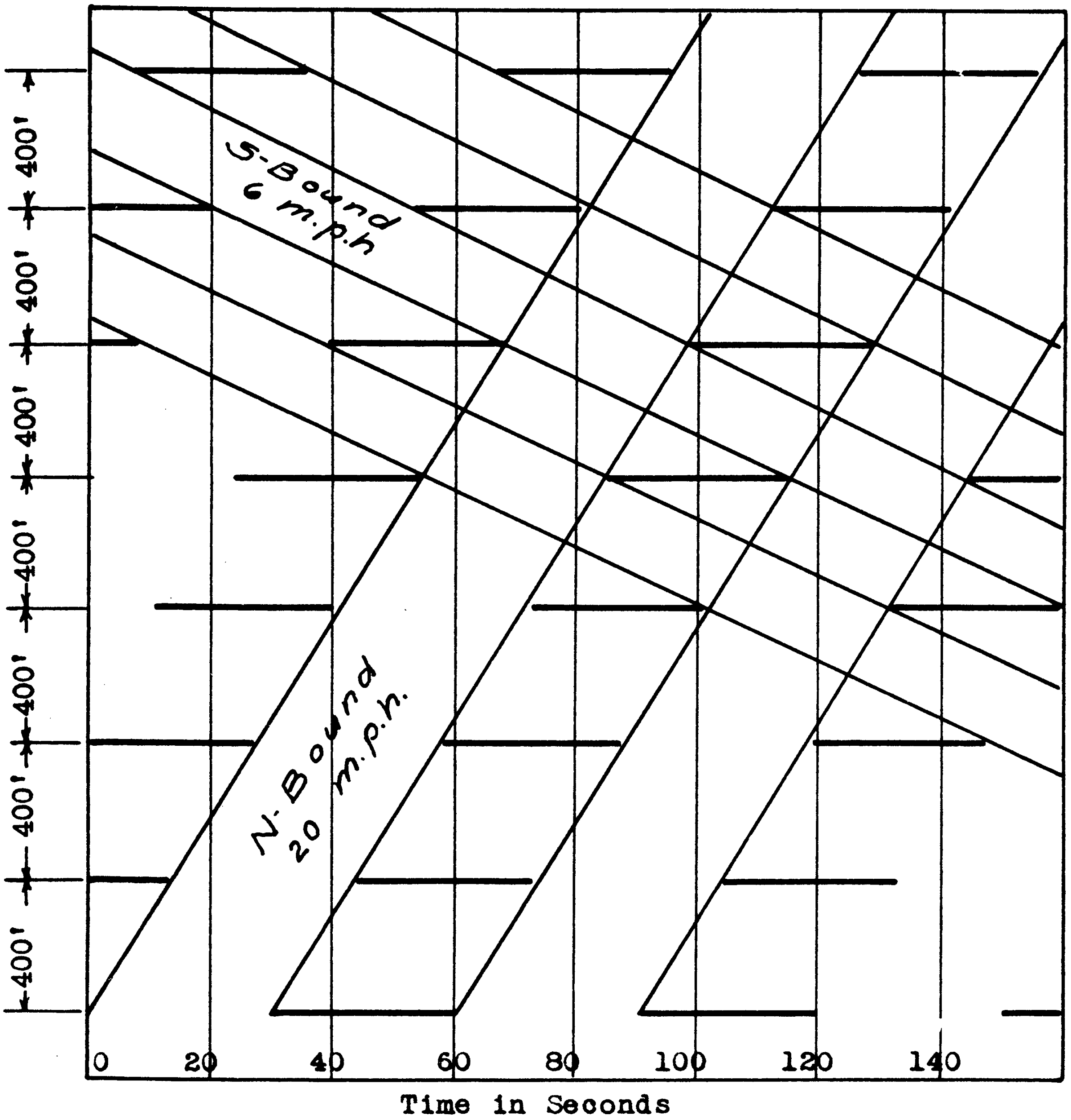


Fig. 18

UNBALANCED CONTROL

FAVORING NORTH-BOUND TRAFFIC

Cycle - 60 sec.

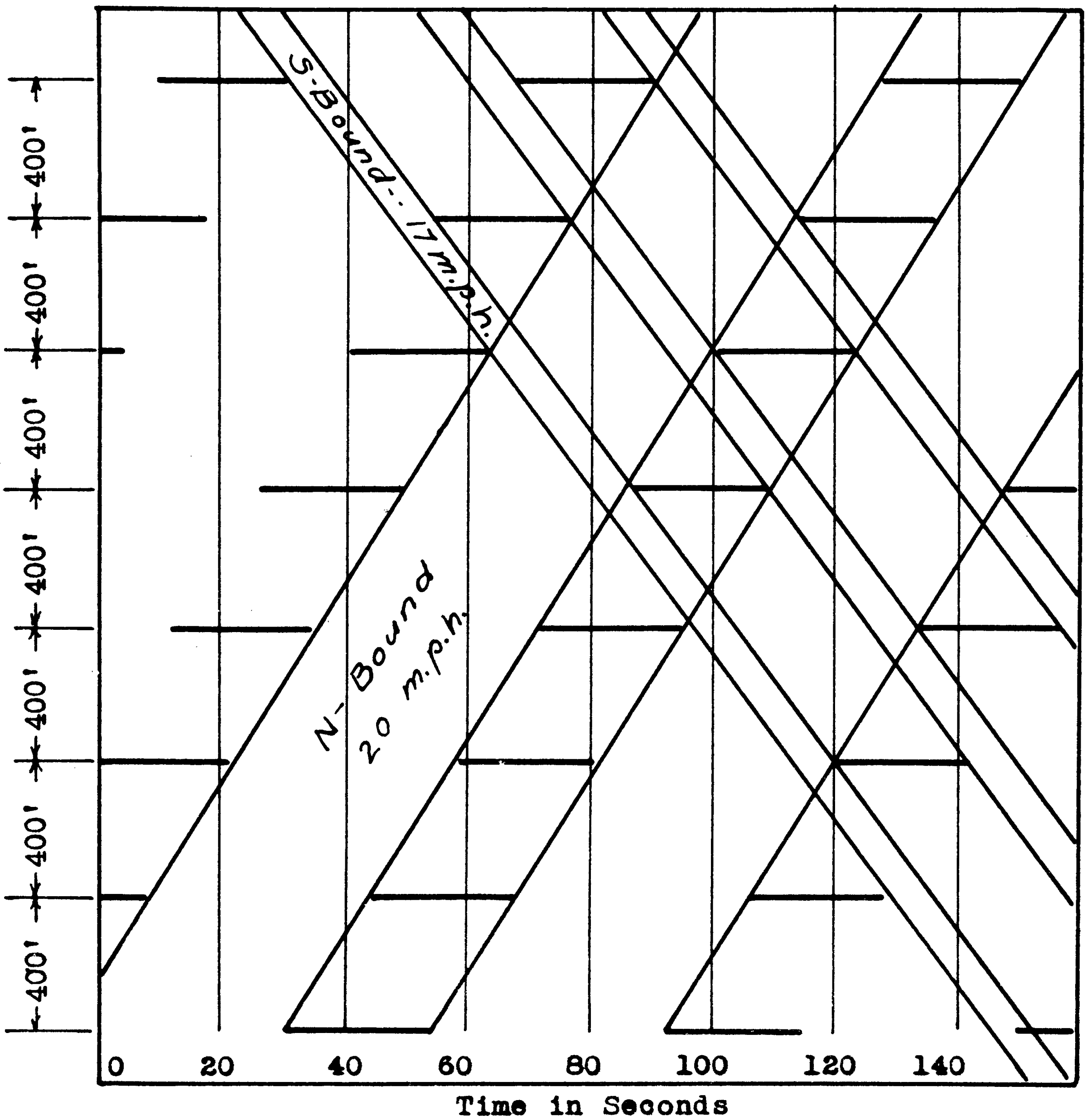


Fig. 19

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CHAPTER VII

TRAFFIC-ACTUATED CONTROL

HISTORICAL DEVELOPMENT

In the evolution of fixed-time automatic traffic control, beginning with the independent signal, and passing through the various phases of signal systems, including the simultaneous, the alternate and flexible progressive, considerable progress had been made during the last decade to adapt this device to the varying demands of modern traffic. The design adopted for Michigan Avenue, Chicago, in 1934, is a typical example of the refinements incorporated into a signal system to provide for some of the many complex elements to be found in street traffic movements.

Yet, notwithstanding these advances, the fact still remained that the fixed-time traffic control signal had some very definite limitations as regards flexibility of operation. With traffic fluctuating even within periods of several minutes, the predetermined cycle is unable to provide for a continuous and convenient movement of traffic.

By the application of invention, ingenuity and research during the past decade, there had evolved a new method of control - the traffic-actuated signal - which promised to meet this demand for a greater degree of flexibility by having the signal indications initiated by the presence or approach of traffic, whether vehicular or pedestrian.

The first installation of traffic-actuated signals was made at Orange and Humphrey Streets, New Haven, Connecticut, in April, 1928. By 1931, this type of signal had been installed in twenty-one states and in over one hundred and fifty communities. Chicago installed a traffic-actuated signal on July 23, 1929, at 53rd Street and Hyde Park Boulevard. Washington, D. C., made its first installation at the end of 1931, and about the middle of 1933, had ordered equipment for fifteen intersections.

In January, 1932, Baltimore had decided to install this new signal at all independent intersections outside the central business district.

Montreal had fifty intersections equipped with traffic-actuated signals in June of 1933. This was the first attempt at such a large scale installation in the business district of a large city where coordination of signals is a desirable feature.

DEFINITIONS

Material for the following definitions pertaining to traffic-actuated control signals are taken from the 1934-Manual, and from publications of the Automatic Signal Corporation.

Traffic-actuated control is that automatic control in which the intervals are initiated or modified by impulses from individual vehicles or pedestrians, or from both.

Full traffic-actuated control is that control in which the length of the green signal interval on each street is continuously modified by the approaching traffic, each vehicle being assured of sufficient time to pass from the detector through the intersection. In this type of control the detectors are used on all approaches to the intersections.

Semi-actuated control uses the detectors only on the minor streets approaching the intersection. Under this plan the main street operates normally with the GO indication, except when traffic on the cross street demands the green light in its favor.

Signal interval, or period, is used in the same sense as for the fixed-time signal, namely, any single indication without change.

Cycle is given its usual meaning to indicate a complete series of signal indications or intervals.

Clearance interval is the interval inserted after the GO and preceding the STOP interval on any street.

Phase, in traffic control, is that part of the signal cycle devoted to any one combination of traffic movements, such as the combination of the green and yellow lights.

Vehicle interval, or vehicle protection interval, is the time required for a vehicle moving at normal speed to reach the center of the intersection after passing over the detector. It is a measure of the maximum time spacing between vehicles which can continue to hold the green signal from opposing waiting traffic. Available range of this interval is from five to ten seconds. With detectors placed about one hundred feet from the intersection, which is an average practice, a vehicle interval of five to seven seconds is the usual setting.

Time extension is the progressive extension of vehicle intervals by successive vehicles crossing the detector approaching the green signal. It is measured from the time that the rear wheels of the car cross the detector. Subsequent cars passing over the detectors within the vehicle interval reset this timing element and extend the green period for one more vehicle interval from that instant, being limited, however, by what is termed the maximum interval.

Maximum interval is the maximum time that continous traffic time spacing, less than the vehicle interval, can hold the green signal from waiting traffic on the opposite street. The timing of the maximum interval on the street having the green signal begins with the arrival of the first car on the street which has the red signal. The available range of the maximum interval is from twenty-five to sixty seconds, the usual setting being from twenty-five to thirty-five seconds.

Initial interval is the starting (green signal) interval inserted before the vehicle interval to allow time for starting traffic to get in motion. The available range of this setting is from three to ten seconds, the usual setting from four to seven seconds.

Vehicle detector, or pressure sensitive unit, is a device located in the street to register the approach of vehicles. It is connected to a relay in the control mechanism, and is actuated by the pressure of a vehicle moving towards the intersection. The detectors are usually placed from seventy-five to one hundred and fifty feet from the crosswalk, depending upon the normal approach speed on the individual street.

METHODS OF ACTUATION

There are several types of traffic-actuated signals, differing especially in the manner employed in detecting the approach of the vehicle.

Detection by Sound

In the G. E. Novalux traffic-actuated signals the operator of the vehicle desiring to get the right-of-way drew near to the curb and sounded his horn. Vibrations engendered by the blast of the horn were picked up by the directional microphone and sound collection box which was located at the right curb of each side of the street, preferably on the main building line and about fifteen feet from the approaching curb line and about ten inches above the road surface. From this point the message was cummunicated to the main control box containing an automatic variable speed timer with a re-set brake. A secondary control box with auxiliary apparatus actuated the control mechanism.

This type of signal was developed in 1928.

Detection by Sound Box in Street

The Adler Sound Light signal, developed in 1931, was operated by vehicles passing over inert hollow steel boxes imbedded in the approaches to the intersection. The steel boxes contained no mechanism, the hollow interior merely concentrating and conveying the sound of the vehicle tires as they passed over the boxes through tubing to the microphones. These converted the sound waves into electrical impulses, whence they were transmitted to the control box, which in turn operated the traffic signals.

Detection by Light

By an adaptation of the photo-electric cell, the presence of traffic was detected by the interruption of a beam of light which was directed from an overhead lamp to a mushroom covering in the street. As the vehicle passed over the mushroom it cast a deep shadow which was recorded on the photo-electric cell, and this message in turn was transmitted to the controller. This form of signal was developed by the Westinghouse Company, Pittsburgh, Pennsylvania, and put into use in 1929.

Detection by Detector Coil in Street - Magnetic Action

A vehicle-actuated control without contact was developed by the Miller Train Control Corporation in 1929. A detector unit, buried under the pavement was composed of two primary and two secondary coils. The functioning parts were housed in a seasoned concrete structure protected by a manganese steel cover. This unit, which operated on the magnetic Wheatstone bridge principle, consisted of two cores of laminated transformer steel, upon which four coils, two primary and two secondary, were wound. Any vehicle passing over this magnetic field sent an impulse to the controller.

The Trafilatore, as this equipment was called, had the relay circuit feature, whereby the circuit worked in conjunction with the standard detector and enabled it to distinguish between moving and standing vehicles. The detector circuits were so designed as to operate on the closed circuit principle, so that any failure in the detector's circuits or its interconnecting cables caused the lights to operate automatically on a pre-timed basis until the circuits were restored to normal.

Detection by Pressure - Treadle Operated

This type of equipment which is almost exclusively used for traffic-actuated control in preference to any of the above mentioned, is composed of two main parts, a set of vehicle-sensitive units or detectors, and the control mechanism.

The vehicle-sensitive units are rubber-covered "sensitive" strips placed in the pavement of the street approaching the intersection. These units operate through pressure only. They relay to the control mechanism all information that is essential for the proper direction of traffic. The control mechanism in its turn receives this information, and with this knowledge regulates the signal light according to the varying flow and volume of the traffic in the streets.

This is an electrostatic method of timing, which makes a new use of well-known electrical principles and employs many of the products of the radio industry, such as condensers, resistors and vacuum tubes.

The pressure sensitive part of the unit is vulcanized into a solid rubber pad, called the pressure sensitive pad, to which is vulcanized an exceptionally heavy tire tread, and both of these are cemented and securely clamped into the casting of a steel rim. This steel casting is about two inches thick and is rigidly fastened to and becomes a part of the highway. In case of a defect or short circuit in the pressure-sensitive unit itself, it can be instantly removed and a new one placed in operation without the pavement being opened. A weight of more than two hundred pounds is required to operate the unit, making it foolproof against interference by children.

The detector can be made uni-directional so that only those vehicles approaching the intersection will send in their impulses, making it impossible for vehicles leaving the intersection on the wrong side of the street to confuse the mechanism.

The detector is also responsive to the speed of the traffic. The wheel of the vehicle being on the unit for a definite distance of its travel along the highway, it becomes possible to measure the speed of the vehicle by the length of the impulse. It further conveys to the control mechanism the knowledge of the exact traffic density in cars per hour, and it "remembers" the presence of cars which have passed over the detectors, but which have not yet been given the right-of-way.

The Control Mechanism is the most important part of this so-called "robot" system. Its function is to receive the impulses from the detectors and assign the right-of-way "intelligently" by means of the signals, in exact accordance with the indications received.

The timing of the various intervals used in traffic-actuated control is based on the principle that a definite time interval is required to charge a condensor to a definite difference in potential through a fixed value of resistance. The control provides for a number of time intervals, each of which is independently adjustable over a suitable range. These different intervals are illustrated in the movement of vehicles through an intersection controlled by this type of mechanism.

Figure 20, which gives a graphic illustration of the features of operation of full traffic-actuated control, as applied to Exchange Place West, Providence, Rhode Island, will aid in following the movement of vehicles through an intersection, and at the same time demonstrate the various intervals and units of time that go to make up a complete series of signal indications in this type of control apparatus.

The horizontal axis indicates the total continuous elapsed time in seconds; the vertical axis represents the phase time in seconds and also the number of cars. Movement on street _A_ is shown above the zero line; and movement on street _B_ below the zero line.

The shaded areas indicate the cars using the intersection and the waiting cars ready to enter the intersection on one phase. The number of cars is represented by the notches in the broken line bordering the shaded areas.

Assume the cars first enter on Street _A_ of which the first two pass the detector before the first car arrives on Street _B_, represented by the point _n_. From this point the cars on Street _A_ are all following within the "vehicle interval", which enables this street to maintain the right-of-way

BASIC FEATURES OF OPERATION

OF TRAFFIC-ACTUATED CONTROL

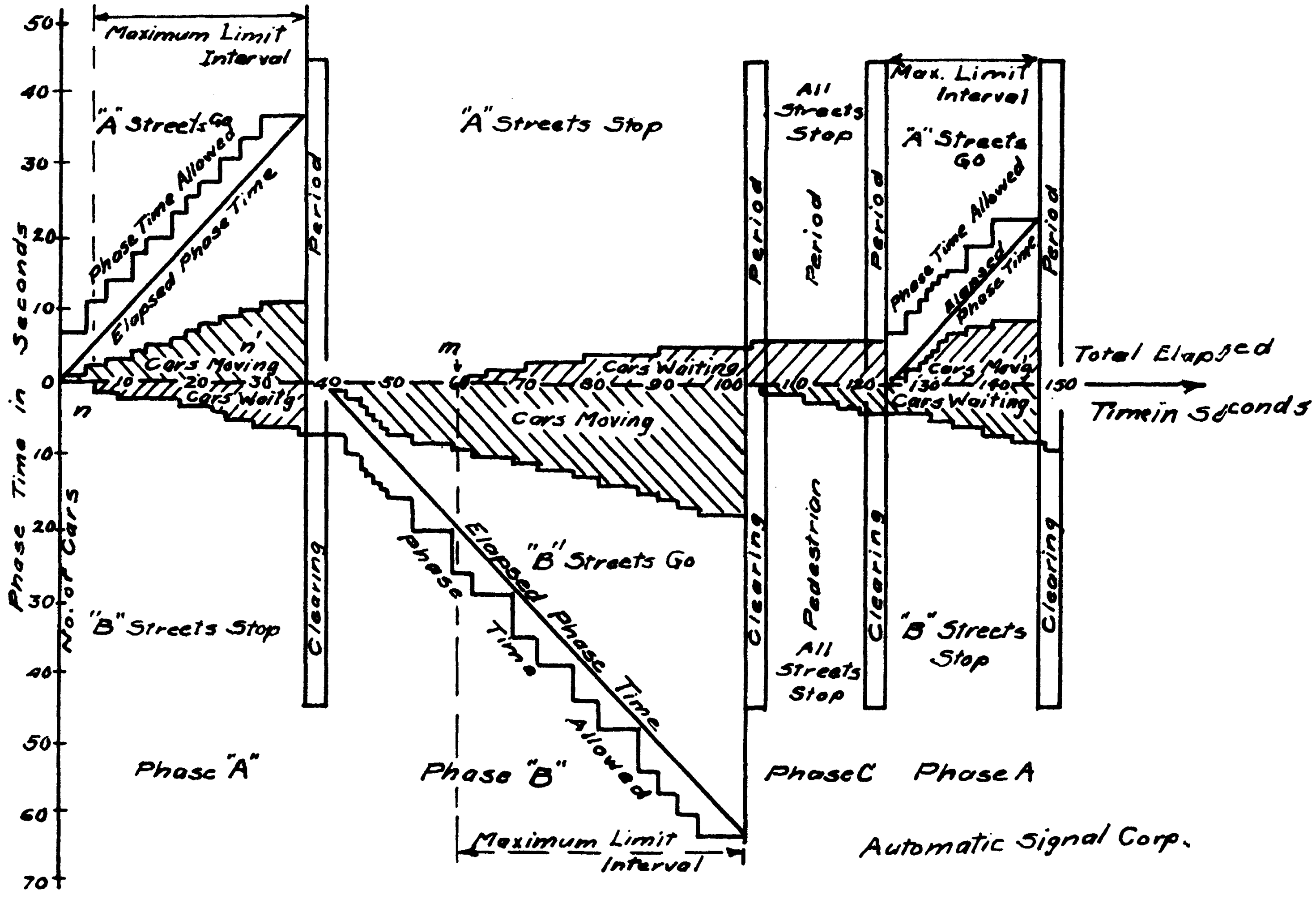

Fig. 20

for a total period represented by the "maximum interval", provided no break occurs in the traffic flow in the meantime. In this example, there was a total of eleven cars entering the intersection on "phase" A during the first thirty-seven seconds of elapsed time, and during the same period, seven cars accumulated at the intersection on Street B, waiting for the right-of-way. The vehicles continued to follow within the "vehicle interval" up to the time allowed for the "maximum interval." If, for example, a break had occurred in the traffic flow on Street A, as at n', to such an extent as to exceed the "vehicle interval", the right-of-way would have been accorded to the traffic on Street B after the expiration of the "clearance interval" period.

Following along the horizontal line a short distance into the next "phase" B, it is seen that these waiting cars move through the intersection within ten seconds from the time at which they first received the right-of-way. After starting, these waiting cars are allowed a period called the "initial interval", affording sufficient time to get into motion. Besides these seven cars, two additional ones also passed in "phase" B before traffic again appeared on Street A. This is indicated on the diagram by the point m where the "maximum interval" begins for Street B. In "phase" B it happens that no break occurred and that the cars continued to move on Street B for the "maximum interval." It is important to note that the timing of the "maximum interval" does not necessarily begin with the timing of the green interval, on any street, but is indicated by the arrival of the first car against the red signal on the opposing street. This "maximum interval" has the effect of constantly changing the maximum green time allowed to each street in accordance with the natural random arrival of vehicles on the opposing street.

"Clearance intervals" are shown following the green in both phases A and B; and after the latter, follows the special pedestrian period as indicated by "phase" C.

"Phase" A begins anew with cars moving on Street A. In this case the "maximum interval" begins immediately after the "clearance period" since four cars had already arrived on Street B during the pedestrian period.

APPLICATION OF TRAFFIC-ACTUATED CONTROL EQUIPMENT

Various applications of this new type of equipment have been found. It can be designed to control the movement of street cars as well as free wheel vehicles. After the car has unloaded, and taken on passengers preparatory to departure, it moves forward a few feet to give its impulse to the detector placed on the trolley, after which it is permitted to proceed at the earliest opportunity.

In the first years of this development it was thought that its application was limited to the isolated intersection. Although it is particularly applicable to such intersections where traffic is extremely unbalanced, and where in the absence of any control the cross traffic is able to pass only with great difficulty, it is now claimed that heavily travelled intersections with balanced traffic can be controlled very efficiently by this method. When vehicle counts are made at intersections for hour or half-hour periods the intersection might be considered to carry a fairly balanced traffic. Recent studies have shown, however, that if counts are made at intervals as small as one-half to one and one-half minutes, very wide variations will be found to exist under conditions of very heavy traffic flow. Full traffic-actuated control equipment possesses the flexibility to follow closely these short period fluctuations with a consequent gain in efficiency.

Complex intersections are handled rather effectively by traffic-actuated control by permitting the simultaneous movement of only those vehicles which do not seriously interfere with each other, meanwhile stopping such movements as would greatly reduce the speed of traffic flow through the intersection.

In 1931 studies were made at a major intersection in Lincoln Park, Chicago, which is controlled by traffic-actuated signals. The traffic count at that time showed 66,300 vehicles in seventeen hours - an hourly average of 3,900, with a maximum hourly flow of 6,000 vehicles. Observations showed clearly the wide variation in cycle lengths allowed, and particularly the extreme variation in the distribution of the cycle between the traffic movements as determined by the actual traffic from cycle to cycle.

A further application is made in connection with the progressive system on thoroughfares where the distance between intersections is so small that full band progressive movement in both directions would be impossible. Chosen intersections are equipped with traffic-actuated signals which show green to the main thoroughfare under normal conditions. Full progressive movement is thus maintained in both directions until cross traffic appears at these intersections, when the co-ordinated system is reduced to a semi-progressive arrangement.

Although traffic-actuated control is used mostly for isolated intersections, coordination of signals is claimed to be possible under this method, without interconnecting the individual units. This claim is based on the theory that traffic-actuated installations have a strong tendency to coordinate themselves in accordance with the actual demands of traffic. This coordination is not dependent upon the speed of traffic nor the frequency of arrival of cross street traffic, but is accomplished by intertiming the various units of the system so that the main traffic flows and the cross street flows weave themselves together naturally and without unnecessary waiting.

In the installation at Montreal, where, in 1933, fifty intersections of the business district were equipped with traffic-actuated units, each intersection was independent of all other intersections. It was found that because of the types of traffic and the characteristics of their movements a high degree of coordination and efficiency in movement could be obtained by the demands of the actual traffic movements upon the units installed. In this system the city was saved the expense of installing underground ducts and cables to interconnect the fifty intersections.

At other times, however, coordination is obtained by electrically connecting the controllers as well as by intertiming the traffic-actuated units. In such cases each controller informs the controllers at the adjacent corners of the actual traffic which is approaching at each instant, and thus assigns the right-of-way in such a manner as to provide for continuous movement of traffic, even though the speed, volume, density and turning ratios of the traffic are different at each successive intersection.

Under this type of operation the master controller regulates the time at which the green light may be given to the cross street, as well as to the main street. It likewise regulates the green period for the main street. It grants the green light to the cross street only when traffic demands it, and will return it to the main artery after the cross traffic has passed, or after the expiration of the maximum interval as determined for the intersection.

The 1934-Manual expresses the opinion that in the absence of more factual data, definite recommendations for the exclusive use of traffic-actuated control in coordinated systems are not warranted.

At intersections having a very heavy left turning movement, it may be necessary to change from the normal two-phase system to a three-phase system. In such a case a third phase is automatically turned on, the control reverting to a two-phase system when the traffic once more becomes normal. Traffic-actuated equipment adapts itself very readily to such a situation.

Where pedestrian movement is usually heavy and demands special treatment, the three-phase system is frequently used. Push-buttons are provided at convenient points, and when the pedestrian desires to cross the intersection he pushes the button, the signal flashes a warning to the vehicular traffic, then stops it and gives the pedestrian the right-of-way. After the maximum pedestrian interval has expired the signal flashes a warning to any other pedestrians who are about to enter the crosswalk that a change of signal is in progress. When the vehicular traffic once has the GO signal, it cannot be returned to the pedestrian until after a predetermined period which is adjustable from thirty to ninety seconds, depending upon conditions. Pedestrians pushing the button are "remembered" by the control, and at the end of the period the right-of-way is accorded them.

When a signal has been installed primarily for pedestrian movement, it is good practice to mark the signal light with some identifying symbol as a warning to both pedestrians and motorists. The letters "PX" have been used for this purpose.

At some intersections where the traffic flow does not require the operation of fixed-time signals continuously for twenty-four hours, the lights are either turned off or are operated on a yellow light. Although the traffic during this period is light, yet, the speed is usually very high. It would therefore appear desirable to have definite control during this time as well as during the period of heavy traffic, in order to provide for safety at the intersection, which can be accomplished by traffic-actuated control.

EXAMPLES OF EFFICIENCY OF TRAFFIC-ACTUATED CONTROL

The State of Massachusetts had conducted a series of delay studies in 1931 with the view of determining the efficiency of the different types of traffic control at intersections. These studies were made on two streets, one having balanced traffic flow, and the other having rather unbalanced traffic.

Intersection A -- Balanced Traffic Flow

Actual flow during the study ranged from five hundred to seven hundred vehicles per hour. The recorded delay was the actual time lost by vehicles standing still while waiting for the signal to turn green. The losses due to deceleration and acceleration were not included since they were assumed to be equal for each type of control.

Type of Control	Delay in Car Seconds	Efficiency-Per Cent Greater than Fixed Cycle Control
Fixed Cycle	9.60	--
Semi-Actuated	8.52	13
Full-Actuated	6.84	29
Intersection B -- Unbalanced Traffic Flow.		
Fixed-Cycle	8.40	--
Semi-Actuated	3.42	59
Full-Actuated	2.76	67

In 1930 the Automatic Signal Corporation carried on some efficiency studies of traffic signals, comprising fixed-time control, semi-vehicle-actuated and full-vehicle-actuated control. Figure 21, gives the results of these observations.

In the same year, another investigation was conducted at the intersection of Glen Avenue and North Regent Street in Port Chester, New York. Observations were made for fixed-time control and for semi-actuated control. The results are shown in Figure 22. The solid lines in the diagram represent the delay curves for fixed-time control, and the dotted lines give the delay curves for vehicle-actuated control. The vertical distance on the graph, from the fixed-time total delay curve to the semi-actuated curve shows the decrease in delay per hour effected by semi-actuated control for various volumes of traffic. Horizontal distances between the same two curves show the increase in capacity in cars per hour for any given amount of delay.

JUSTIFICATION FOR INSTALLATION OF TRAFFIC-ACTUATED CONTROL SIGNALS AS RECOMMENDED BY THE 1934-MANUAL

The three elements determining the economic justification for traffic control signals-reduced delays, reduced accidents and orderly and convenient movement of traffic-apply to traffic-actuated control as well as to fixed-time control.

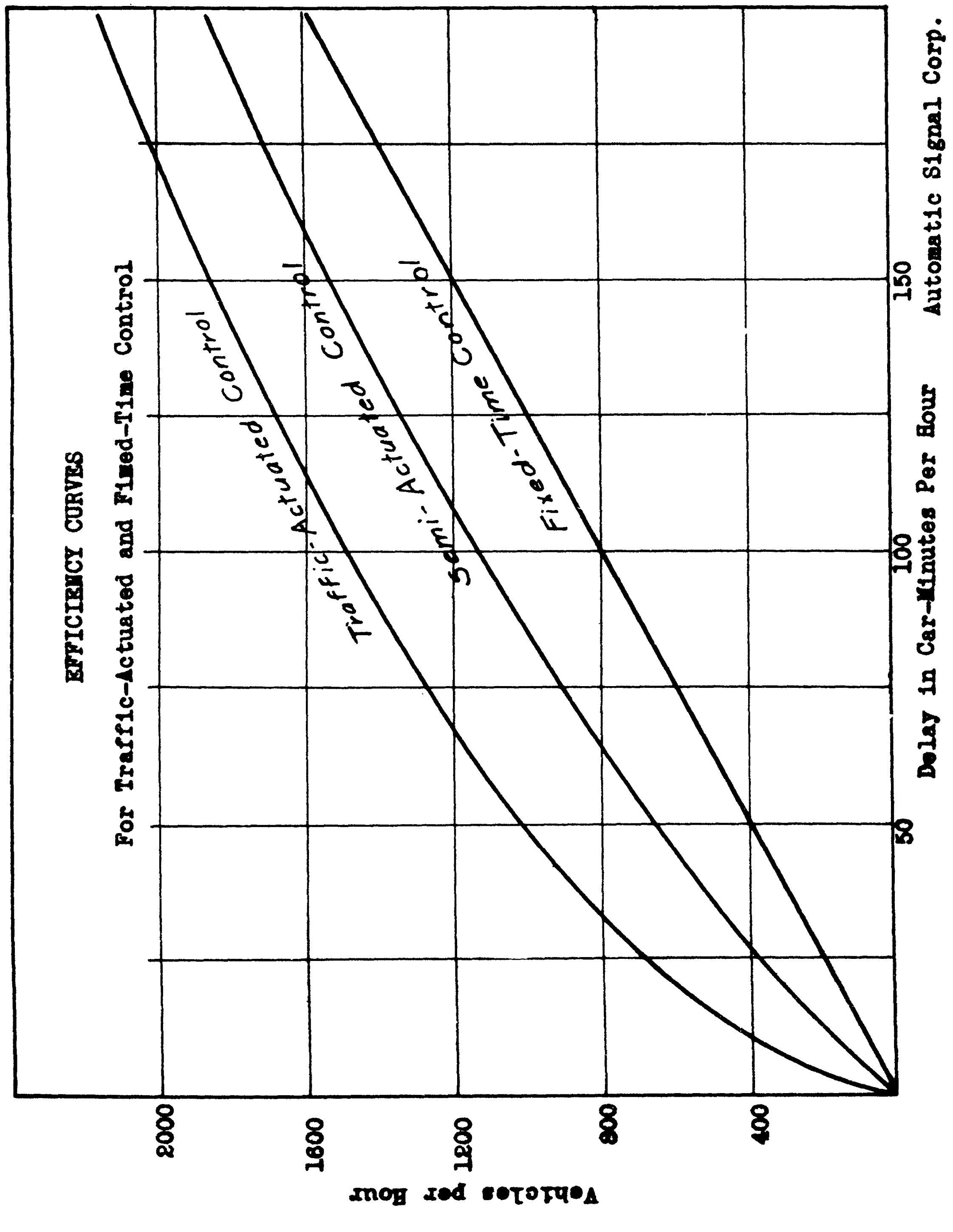
EFFICIENCY CURVES
For Traffic-Actuated and Fixed-Time Control
Traffic-Actuated Control
Semi-Actuated Control
Fixed-Time Control
Vehicles per Hour
2000
1600
1200
800
400
50
100
150
Delay in Car-Minutes Per Hour
Automatic Signal Corp.

Fig. 21

Of the seven warrants as prescribed by the 1934-Manual for the installation of fixed-time traffic control signals, the following may be considered as sound measures for traffic-actuated control as well.

1. Vehicular volume.
2. Heavy left turning movement.
3. Pedestrian movement.
4. Accident hazards.
5. Combination of warrants.

It is further recommended that in case the minimum requirements justifying installation of fixed-time signals are not met, the traffic-actuated type may be reasonably employed.

Exception is made relative to the two warrants, namely, coordinated movement and through stop streets.

(a) When non-interconnected synchronous motors are used in a coordinated system, the traffic-actuated control shall not be used at any of these intersections. If, however, these individual controllers are interconnected with a master controller, forming part of a flexible progressive system, the traffic-actuated equipment might be used at some intersections. In this case the cross street at an intersection thus equipped cannot get the GO indication during the regular GO band on the main street, but can demand it at any other period.

(b) The Through Stop Street warrant provides for better pedestrian movement and speed control at chosen intersections on a through street with heavy traffic, the former of these benefits will be better procured by the traffic-actuated control, but speed control on such through streets will not be obtained by this method.

ADVANTAGES OF TRAFFIC-ACTUATED CONTROL SIGNALS OVER FIXED-TIME SIGNALS

In summarizing what has been previously said about traffic-actuated control and its relation to fixed-time control, the advantages of the former have been listed by the manufacturer as follows:

1. Less delay.

2. Encourages respect and obedience of motorists and pedestrians because of reduction of unnecessary delays.

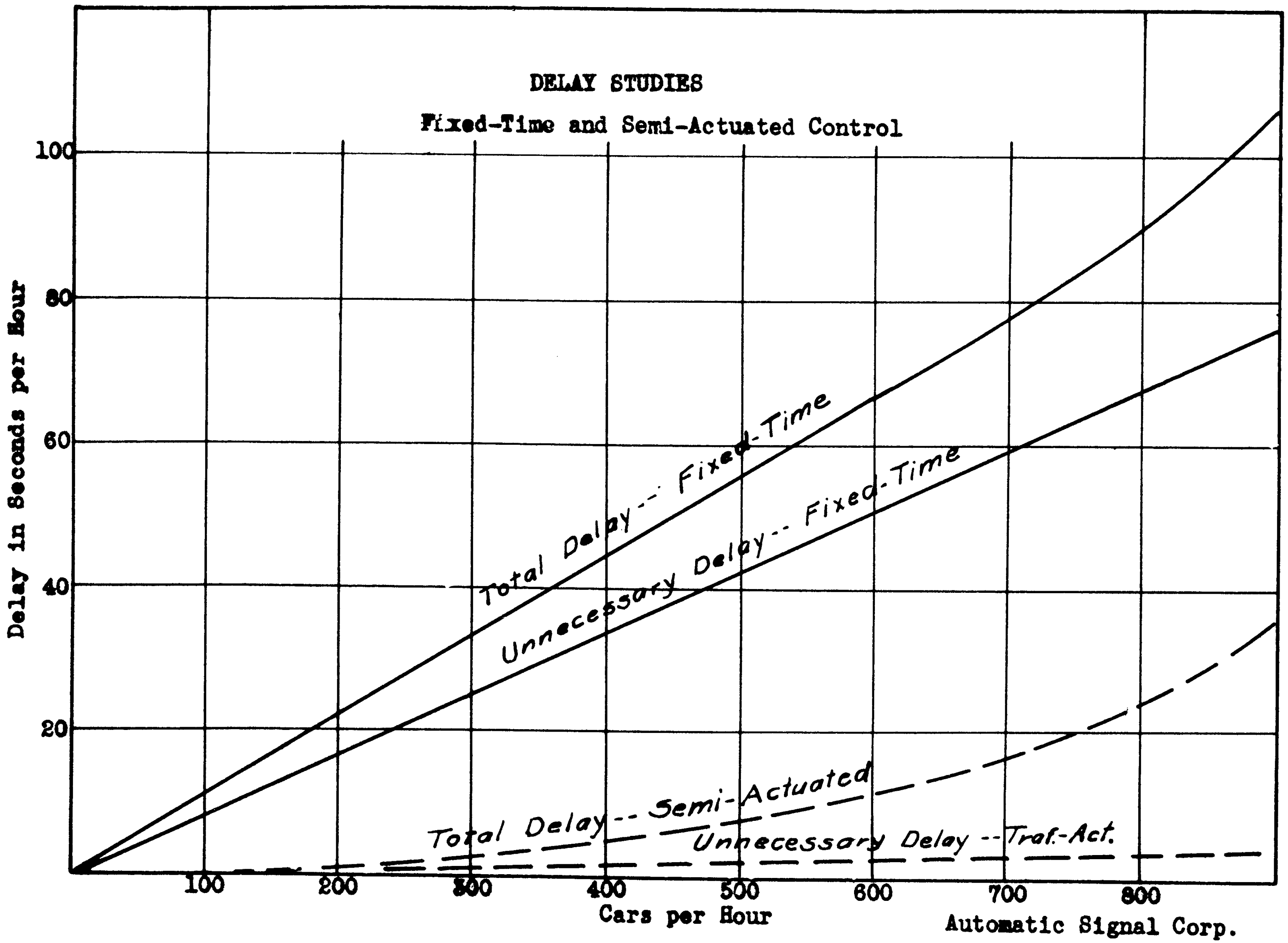
DELAY STUDIES
Fixed-Time and Semi-Actuated Control
Total Delay -- Fixed-Time
Unnecessary Delay -- Fixed-Time
Total Delay -- Semi-Actuated
Unnecessary Delay -- Traf.-Act.
Delay in Seconds per Hour
100
80
60
40
20
100
200
300
400
500
600
700
800
Cars per Hour
Automatic Signal Corp.

Fig. 22

3. More orderly and convenient movement because it is more responsive to the variable traffic demands.

4. Less tendency to avoid signalized intersections.

5. More logical routing of traffic.

6. Fewer demands for signals.

7. More effective in reducing or preventing accidents because it removes one of the causes for violation of signals and affords continuous operation without undue delays.

8. Well adapted to independent multiple intersections where special conflicting movements call for consideration.

As discussed briefly in Chapter VI, the Bureau of Public Roads in the summer of 1932 conducted an investigation at the intersection of Constitution Avenue and Seventeenth Street, Washington, D. C., to determine the relative efficiency of different methods of traffic control. Observations were made with traffic moving under no control, officer control, vehicle-actuated control and fixed-time control - the latter included seventeen different cycles.

The observations were confined to the hours between 9:30 A.M. and 4:15 P.M. in order to avoid the morning and afternoon rush hours. In this manner there was a steady flow of traffic, averaging about two thousand vehicles per hour. This was a strictly independent intersection, as there were no controlled intersections in the neighborhood.

Of the three flexible methods, including no control, officer control and traffic-actuated control, operation without control resulted in the least delay to traffic and produced the highest flexibility of movement, since it was possible to have vehicles enter the intersection from the different streets at one time. In stating this conclusion, it was realized that it would not hold for unlimited volumes of traffic, the prevailing average being about two thousand vehicles per hour.

Of all the control methods, officer control permitted the fastest movement of traffic, closely followed by the shortest fixed-time control (15 - 15 cycle), and traffic-actuated control. Traffic-actuated control and the 15 - 15 fixed-time setting showed practically the same efficiency in movement of traffic through the intersection for that volume of traffic. It was felt, however, that this short fixed cycle would prove ineffective in very heavy traffic, due to the tendency of vehicles to run through the yellow and into the red interval under such conditions, which in the rush-hour traffic would likely result in dangerous confusion.

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Traffic Signal Controlled by Magnetism - Staff Article, Engineering News-Record, June 23, 1931; p. 158.

Actuated Signals for Baltimore - Staff Article, American City, January, 1932; p. 110.

Traffic-Light Placement and Traffic-Control Costs Studied in Pittsburgh, Pennsylvania,-Staff Article, American City, January, 1933; p. 82.

Effect of Control Methods on Traffic Flow - E. H. Holmes, Public Roads, February, 1934; pp. 233-242.

CHAPTER VIII

INVESTIGATION OF LEFT-TURNING VEHICLES AT SIGNALIZED INTERSECTIONS

In the mathematical formulas proposed for the timing of traffic control signals the cycle length is essentially a function of the speed and volume of the vehicular traffic. These formulas were derived on the assumption that there were no obstacles to free traffic movement, such as the left or right turns.

The turning vehicles were thus assumed to be non-existent in order to simplify the mathematical treatment of the problem, for when taking into consideration the influence exerted by this turning element on the traffic flow, the complexity of the problem soon becomes apparent. Furthermore, the absence of factual data made it impossible to evaluate this factor.

FIELD WORK IN COLLECTING DATA FOR LEFT-TURNING VEHICLES

The following investigation was undertaken for the purpose of analyzing the different elements of left-turning traffic, with the view of determining their significance as a retarding influence upon the traffic passing through the intersection.

In carrying out this work, use was made of the photographic method developed by Dr. Bruce D. Greenshields, Professor of Engineering Science at Denison University, in connection with a research project in traffic control which was carried on at the University of Michigan.

The equipment consisted of a sixteen-mm Simplex motion picture camera, so arranged as to be able to take pictures at any definite interval of time, for instance, in this study the time interval for the pictures lay between 1.0 and 1.5 seconds. The camera was mounted on a tripod, and actuated by a rebuilt electric windshield wiper and a storage battery. In this way the still pictures were obtained. A fifty-foot sixteen-mm film gave two thousand pictures. Further data relative to the field work is found in the accompanying Table I.

METHOD OF COLLECTING DATA FROM PICTURES

The pictures were thrown on a screen by means of a

TABLE I

GENERAL INFORMATION ON INTERSECTIONS
INVESTIGATED FOR LEFT-TURNING MOVEMENTS

Location	Position of Camera	Time of Day	Traffic Volume Vehicles per hour	Left Turns	Signal Cycle in Seconds	Time Interval of Pictures in Sec.	No. of Pictures Taken
Main-Huron, Ann Arbor, Mich.	10th Story, First National Bank Bldg., One block away	11:30-12:15 AM	1180	90	76	1.0-1.5	2000
Fort-Cass Detroit, Mich.	5th Story, Factory building One-half block away	10:30-11:15 AM	2480	175	59	1.0-1.5	2000
Michigan-Trumbull, Detroit, Mich.	Top of Baseball Grandstand - Navin Field, One-half block away	12:00-12:45 PM 3:45-4:15 PM	1960 2120	196	69	1.0-1.5	4000
Michigan-Cass, Detroit, Mich.	10th Story, Michigan Bell Telephone Bldg. One-half block away	12:00-12:45 PM	2040	60	59	1.0-1.5	1100

projector that made it possible to observe the individual frames as still pictures. The screen, as shown in Exhibit A, consisted of a sheet of $8\frac{1}{2}$ x 11 inch paper, with the intersection drawn in perspective. This outline was sketched whilst the picture was shown. The screen was divided into ten-foot squares which made it possible to locate the relative positions of the vehicles as they passed through the intersection.

A plan of the intersection was likewise drawn to scale on $8\frac{1}{2}$ x 11 inch paper and cross sectioned with ten-foot squares to correspond to the divisions on the screen. This plan, is shown in Exhibit B. The extension of the center line of the roadway divided the intersection into what might be termed "Zones of Influence." Zone 1, for any direction was that portion of the intersection to the right of the center line, with the outer edges of the crosswalks as the other boundary lines. Zone 2, was the area of the intersection to the left of the center line. As long as the turning vehicles were still to the right of this center line, they were considered as a potential obstacle to the vehicles following in the center lane of traffic. After crossing the center line, into Zone 2, they might be a cause of delay to vehicles coming in the opposite direction. Thus Zone 1, for east-bound traffic becomes Zone 2, for west-bound traffic.

As the pictures were thrown on the screen and the position of the vehicle spotted on the plan, each point indicated its progress in the time or picture interval under which the camera was operating. By joining these points, the course of the vehicles was definitely outlined. The grouping of several points indicates that the vehicle was forced to come to a complete stop during a corresponding number of pictures.

The distances traveled by the different vehicles in Zones 1 and 2, were scaled and recorded in the horizontal line 1 on the data sheet, as shown in Exhibit C. In determining the distances in Zone 1, a vehicle length of fifteen feet was assumed, which was added to the distance traveled from the outer crosswalk line to the point where the vehicle crossed the center line. The number of points in the respective zones was then determined and entered in line 2 of the data sheet. Multiplying these values in line 2, by the corresponding time interval between pictures, gave the time in seconds required to traverse this zone; these values are shown in line 3. The figures in line 1, divided by those in line 3 gave the average speed in feet per second, as shown in line 4. Line 5 gave the speed in miles per hour.

INTERSECTION IN PERSPECTIVE

Used as Screen for Projecting Pictures

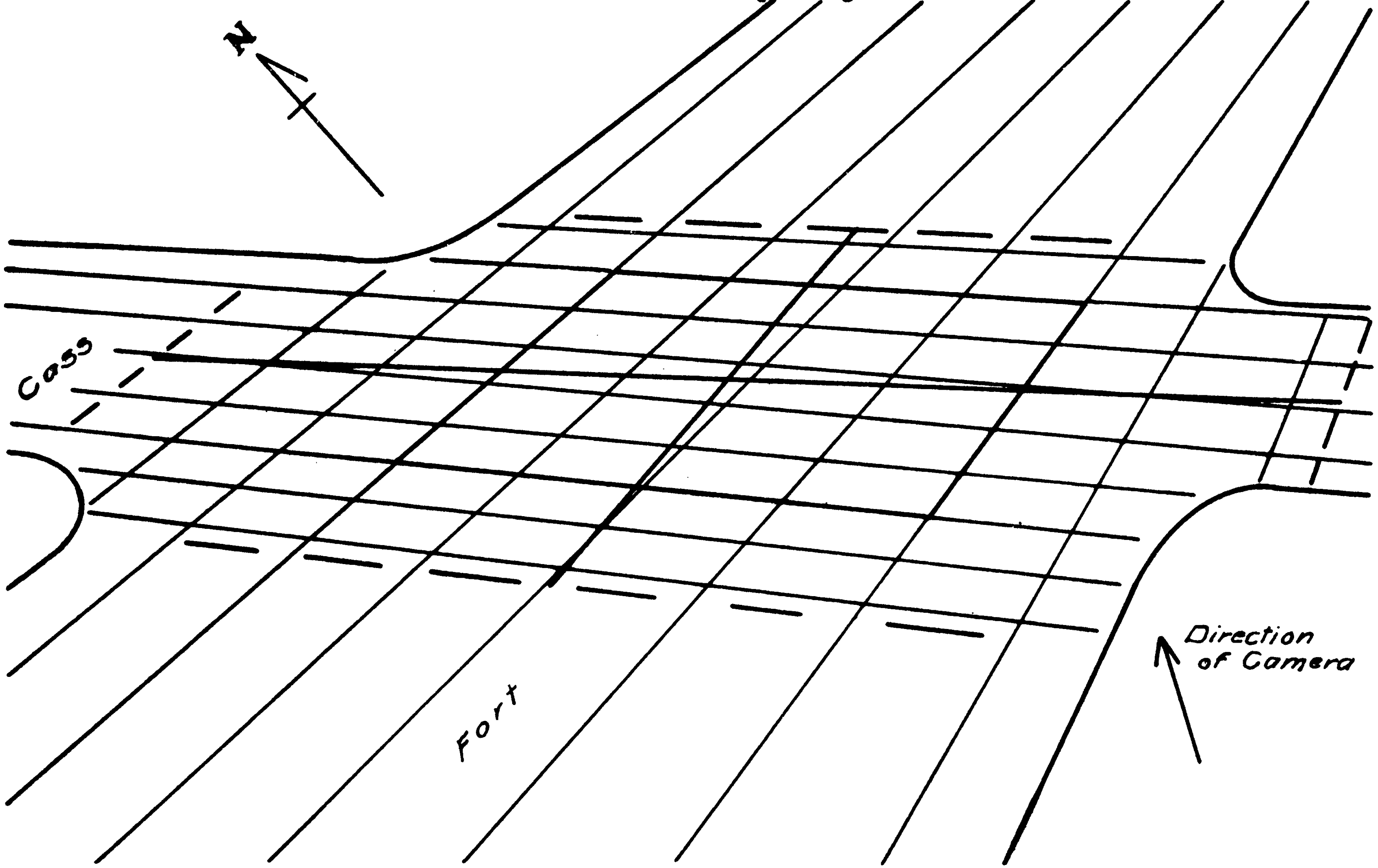
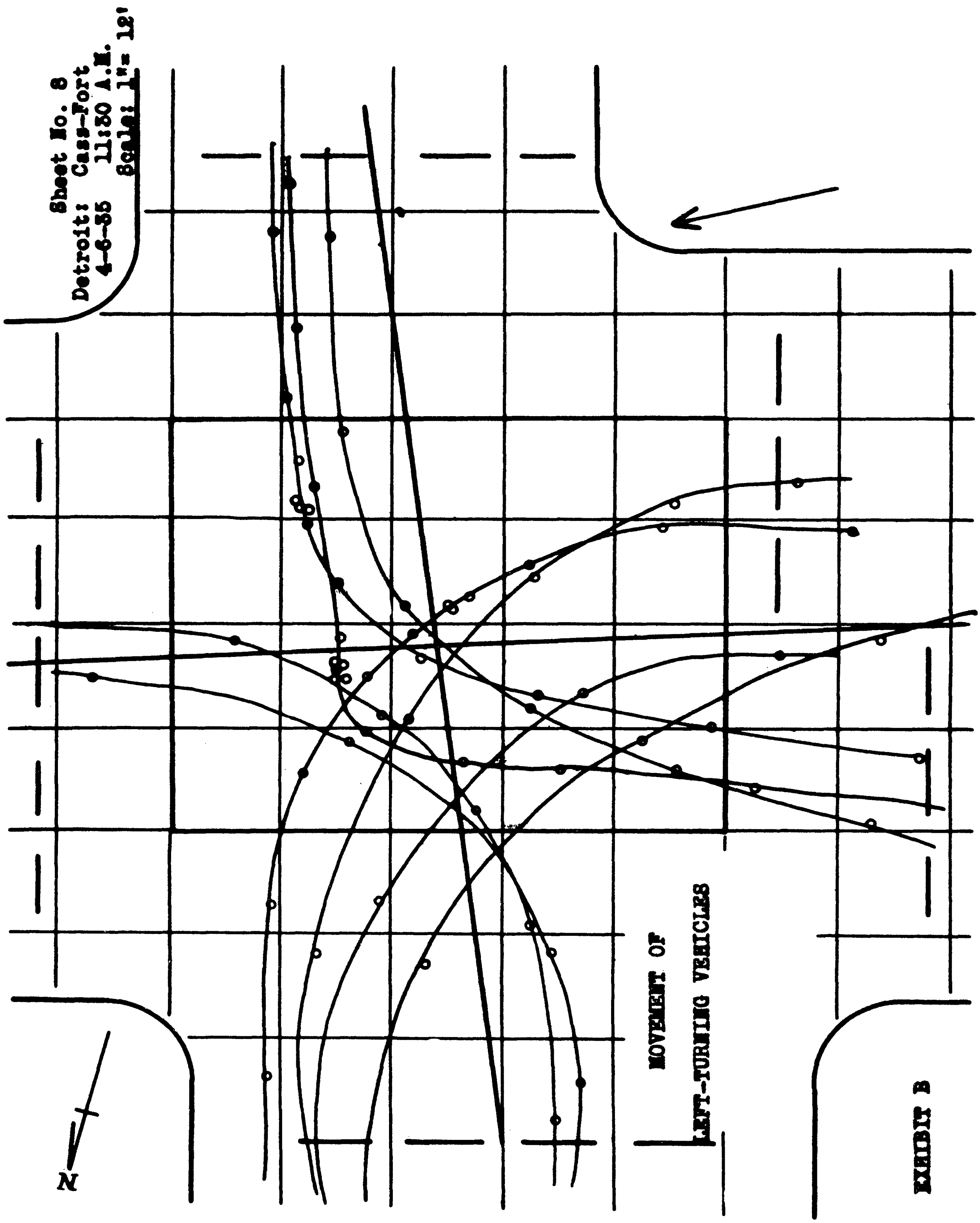


Exhibit A


Sheet No. 8
Detroit: Cass-Fort
4-6-35 11:30 A.M.
Scale: 1"= 12'
MOVEMENT OF
LEFT-TURNING VEHICLES
N
EXHIBIT B

DATA SHEET FOR LEFT-TURNING VEHICLES

Sheet No. 1-2

Photograph Speed: 1.23 Fort-Cass Date: 5-6-35

Left-Turns

		N-Bound 1	2	3	4	5	6	7	8	9	10		S-Bound 1	2	3	4	5	6	7	8	9	10
Zone 1	1	66	63	59	67	87	60	65				S - ft.	58	67	48	66	35	48	38	50		
	2	4.2	7.8	5.9	3.5	8.5	2.7	10.6				t - Picture Intervals	10.5	6.7	8.3	10.7	2.8	2.3	1.6	8.9		
	3	5.2	9.7	7.3	6.8	10.5	3.3	12.9				T - Sec.	13.0	8.3	10.3	13.3	3.5	2.8	2.0	10.9		
	4	12.6	6.5	8.0	9.8	8.2	18.0	5.0				v - ft/sec	4.5	8.1	4.7	5.0	10.0	17.1	19.5	4.6		
	5	6.6	4.4	5.5	6.7	5.6	12.3	3.4				V - m.p.h.	3.1	5.5	3.2	3.4	6.8	11.7	13.3	3.1		
Zones 1-2	1	109	100	99	103	120	104	102				S	81	85	74	89	62	74	68	75		
	2	6.2	10.8	9.0	7.0	9.9	4.3	11.4				t	12.0	7.7	10.0	12.3	4.3	3.2	2.7	10.4		
	3	7.7	13.4	11.6	8.7	12.3	5.4	13.9				T	14.9	9.6	12.4	15.3	5.3	3.9	3.3	12.7		
	4	13.9	7.5	8.8	11.8	9.8	19.3	7.4				v	5.4	8.9	6.0	5.8	11.7	19.0	20.6	5.9		
	5	9.5	5.1	6.0	8.0	6.7	13.2	5.0	~~7.6~~	~~6.1~~		V	3.7	6.0	4.1	3.9	8.0	13.0	14.0	4.0		

Exhibit C

ANALYSIS OF DATA TO OBTAIN AVERAGE INTERSECTION SPEEDS

The summary sheet as shown in Exhibit D combines the speeds of the turning vehicles - as taken from line 5 of Exhibit C - in groups, which are further summarized into totals for intervals of one m.p.h. The final totals from these sheets are combined in Table II. Column A gives the frequency of occurrence of speeds within the limits of one m.p.h. Columns B and C give the cumulative frequencies and cumulative percentages, respectively. These latter values formed the basis for the construction of the diagrams as shown in Figures 23 to 33, inclusive.

These diagrams are drawn on Arithmetic Probability paper, designed by Hazen, Whipple and Fuller, and represent the frequency distribution of the vehicle speeds in such a manner as to give a straight line variation of the frequency of occurrence of the different speeds.

Speeds in m.p.h. are represented as ordinates, and percentage of vehicles traveling at speeds less than the speed in question are given by the lower abscissas - the reverse, or percentage of vehicles traveling at speeds equal to or greater than the chosen speed, is shown by the figures at the top of the sheet.

Example:- Following the horizontal line in Figure 23, corresponding to a speed of eight m.p.h. until the diagonal line which represents the north and south bound traffic is met, and at this point dropping vertically to the base line, it is seen that about eighty-two per cent of the left-turning vehicles travel at speeds of eight m.p.h. or less; or, passing vertically to the upper figures, it is seen that eighteen per cent of the left-turning vehicles pass through Zone 1 at speeds higher than eight m.p.h.

Passing vertically from the fifty per cent mark on the abscissa base line to the diagonals, the median average speeds for the different groups of vehicles are obtained, namely, 3.9, 5.0, and 7.5 m.p.h., for the N-S bound, the N-S.E-W bound and the E-W bound vehicles, respectively.

Figures 23, 24 and 25 show the distribution of average speeds of left-turning vehicles in Zone 1 for all four directions.

Figures 26, 27, 28 and 29 give the average speeds of vehicles in Zone 1 and Zone 2 combined, that is, for the time elapsed between entering and leaving the intersection, as shown in Exhibit B.

Figures 30, 31, 32 and 33 give the average speeds of vehicles passing straight through the intersection under various conditions of starting from rest, not starting from rest and in groups, and not starting from rest, but not traveling in groups.

If the average values for speeds of vehicles going straight through the intersection in groups are taken from diagrams (d'), (f'), (k') and (b') of Figures 30, 31, 32 and 33 respectively, and transferred to Figures 23, 24, 28 and 25, representing the left-turning speeds, and extended horizontally until they meet any of the frequency distribution lines, the point where the horizontal and diagonal lines meet, when extended downward vertically, gives the maximum per cent of left turning vehicles which cause delay to traffic using the same lane from which the turns are made. This is illustrated by the following example.

Figure 30, diagram (d') gives the average speed of thirteen and five tenths m.p.h. for vehicles in groups, passing straight through without any delay. This constitutes the optimum condition for the most efficient use of the intersection. Transfer this value of thirteen and five tenths m.p.h. to Figure 23, and pass horizontally to diagram (c) for the corresponding direction. It is seen that ninety-six per cent of all left-turning vehicles are traveling at average speeds such as to delay the through traffic in the intersection. Diagram (c) represents speeds for vehicles entering the intersection from all four directions. Taking the N and S-bound vehicles as shown in diagram (a), and the E and W-bound vehicles as in diagram (b), of Figure 23 it is seen that ninety-eight and eighty-eight per cent, respectively, of the left-turning vehicles present a potential cause of delay to traffic passing through at the average speed of thirteen and five tenths m.p.h.

DATA SHEET FOR INTERSECTION SPEEDS

Left Turns-- Zone 1 | **Michigan-Trumbull**

N-S Bound

mph	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	Total Freq.	Cum. Total	Cum. %	Total Speeds
0				/										
1				//	/		/		/	//	7	7	5.3	11.2
2			/		///	/		/		/	7	14	10.5	17.4
3	//	////		///		//	/	////	///	///	22	36	27.1	76.8
4	/	//	/	/	///	/	//	//	//		15	51	38.3	66.6
5	///		/	/		//	//	//	//	/	14	65	48.8	76.6
6	/		/	////	/	///	//	///			15	80	60.1	96.6
7	~~////~~		//		/			/	//	/	12	92	69.1	88.0
8	//			//	//	///				/	10	102	76.6	83.8
9	/	//	/	/	//	/	/		/		10	112	84.1	93.4
10		/					/				2	114	85.6	20.7
11				/			/				2	116	87.2	22.9
12							/	/			2	118	88.6	25.3
13		/					/				2	120	90.1	26.7
14		/	/			/		/			4	124	93.1	57.5
15	x			x						/	1	125	93.9	15.9
16	/		/								2	127	95.4	32.2
17						/	x				1	128	96.1	17.0
18						/	/			/	3	131	98.4	55.8
19						/					1	132	99.1	19.4
20	/										1	133	100.0	20.0
											133			923.0
											Mean	Average	Speed	= 6.9 m.p.h.

Exhibit D

TABLE II

SUMMARY SHEET OF INTERSECTION SPEEDS

FORT-CASS

m.p.h.	L-Turns, Z_1 Fig. 23 (a) A	B	C	L-Turns, Z_2 Fig. 23 (b) A	B	C	L-Turns, Z_1 Fig. 23 (c) A	B	C
0	1	1	0.8				1	1	0.6
1	7	8	0.8	3	3	5.6	10	11	6.4
2	25	33	28.0	6	9	17.0	31	42	24.7
3	19	52	44.5	4	13	29.4	23	65	38.2
4	10	62	53.0	5	18	33.9	15	80	47.0
5	16	78	66.6	3	21	39.6	19	99	58.1
6	12	90	72.0	4	25	47.0	16	115	67.6
7	11	101	86.3	3	28	52.8	14	129	75.8
8	4	105	89.8	6	34	64.0	10	139	81.7
9	3	108	92.3	3	37	69.6	6	145	85.2
10	1	109	93.1	2	39	73.5	3	148	87.0
11	2	111	95.0	2	41	77.2	4	152	89.4
12	2	113	96.5	3	44	82.9	5	157	92.3
13	1	114	97.5	3	47	88.5	4	161	94.6
14	0	114	97.5	2	49	92.3	2	163	95.9
15	0	114	97.5	0	49	92.3	0	163	95.9
16	1	115	98.4	0	49	92.3	1	164	96.4
17	2	117	100.0	2	51	96.0	4	168	98.8
18				1	52	98.0	1	169	99.4
19				0	52	98.0	0	169	99.4
20				1	53	100.0	1	170	100.0

Column A;- Frequency of occurrence of speeds within the limits of one m.p.h.

Column B;- Cumulative totals of these frequencies

Column C;- Cumulative percentages.

Z_1, Z_2 Represent "Zones of Influence"
See Exhibit B, page 4.

TABLE II (Cont'd.)

FORT-CLASS

m.p.h.	L-Turns Z_{1-2} Fig. 27 (m)			L-Turns Z_{1-2} Fig. 27 (n)			L-Turns Z_{1-2} Fig. 27 (o)		
	A	B	C	A	B	C	A	B	C
1	3	3	2.6	2	2	3.7	5	5	2.9
2	20	23	19.6	2	4	7.4	22	27	15.8
3	16	39	33.3	3	7	12.9	19	46	26.9
4	13	52	44.4	6	13	24.1	19	65	38.0
5	15	67	57.2	11	24	44.4	26	91	53.2
6	13	80	68.2	1	25	46.2	14	105	61.4
7	13	93	79.4	7	32	59.2	20	125	73.1
8	10	103	88.2	2	34	63.2	12	137	80.0
9	5	108	92.6	1	35	64.8	6	143	83.6
10	1	109	93.5	6	41	76.0	7	150	87.7
11	4	113	96.9	0	41	76.0	4	154	90.0
12	0	113	96.9	3	44	81.4	3	157	91.8
13	2	115	98.6	4	48	88.8	6	163	95.3
14	1	116	99.4	0	48	88.8	1	164	95.8
15	0	116	99.4	4	52	96.2	4	168	98.2
16	0	116	99.4	0	52	96.2	0	168	98.2
17	0	116	99.4	2	54	100.0	2	170	99.4
18	1	117	100.0				1	171	100.0
19									
20									

m.p.h.	Str. Through Fig. 30 - (c')			Str. Through Fig. 30 - (d')			Str. Through Fig. 30 (e')		
	A	B	C	A	B	C	A	B	C
6	3	3	7.3						
7	0	3	7.3						
8	2	5	12.2	2	2	2.0			
9	10	15	36.6	5	7	7.1			
10	11	26	63.5	3	10	10.0			
11	4	30	73.2	12	22	22.5			
12	6	36	87.9	14	36	36.8	5	5	7.2
13	2	38	92.7	18	54	55.1	4	9	13.0
14	1	39	95.1	13	67	68.3	5	14	20.3
15	1	40	97.6	11	78	79.6	7	21	30.4
16	1	41	100.0	11	89	91.0	5	26	37.7
17				5	94	96.0	6	32	46.3
18				1	95	97.0	8	40	58.0
19				3	98	100.0	7	47	68.1
20							6	53	76.8
21							4	57	82.4
22							5	62	89.8
23							2	64	92.7
24							5	69	100.0

TABLE II (CONT'D.)

MICHIGAN-TRUMBULL

m.p.h.	L-Turns Z_1 Fig. 24 (d) A	B	C	L-Turns Z_2 Fig. 24 (e) A	B	C	L-Turns Z_2 Fig. 24 (f) A	B	C
1	7	7	5.3	1	1	2.0	8	8	4.3
2	7	14	10.5	6	7	13.7	13	21	10.9
3	22	36	27.1	8	15	29.4	30	51	27.7
4	15	51	38.3	4	19	37.2	19	70	38.0
5	14	65	48.8	3	22	43.1	17	87	47.2
6	15	80	60.1	3	25	49.0	18	105	57.1
7	12	92	69.1	2	27	52.9	14	119	64.7
8	10	102	76.6	5	32	62.8	15	134	72.8
9	10	112	84.1	2	34	66.6	12	146	79.3
10	2	114	85.6	1	35	68.6	3	149	82.0
11	2	116	87.2	3	38	74.5	5	154	83.7
12	2	118	88.6	2	40	78.4	4	158	85.9
13	2	120	90.1	2	42	82.3	4	162	88.0
14	4	125	93.1	1	43	84.2	5	167	90.8
15	1	125	93.9	3	46	90.2	4	171	93.0
16	2	127	95.4	1	47	92.1	3	174	94.5
17	1	128	96.1	0	47	92.1	1	175	95.1
18	3	131	98.4	1	48	94.1	4	179	97.3
19	1	132	99.1	2	50	98.0	3	182	99.0
20	1	133	100.0	0	50	98.0	1	183	99.4
21				0	50	98.0	0	183	99.4
22				0	50	98.0	0	183	99.4
23				1	51	100.0	1	184	100.0

m.p.h.	L-Turns Z_{1-2} Fig. 27 (p) A	B	C	L-Turns Z_{1-2} Fig. 27 (q) A	B	C	L-Turns Z_{1-2} Fig. 27 (r) A	B	C
1	5	5	3.7	1	1	2.0	1	1	0.5
2	9	14	10.5	3	4	7.8	8	9	4.9
3	20	34	25.5	8	12	23.5	17	26	14.1
4	17	51	38.3	4	16	31.4	24	50	27.2
5	11	62	46.6	5	21	41.1	22	72	39.1
6	14	76	57.1	2	23	45.1	13	85	46.1
7	9	85	63.8	6	29	56.9	20	105	57.1
8	12	97	72.8	2	31	60.7	11	116	63.1
9	12	109	82.0	4	35	68.6	16	132	71.8
10	1	110	82.7	0	35	68.6	12	144	78.2
11	2	112	84.2	6	41	80.4	7	151	82.1
12	3	115	86.5	2	43	84.3	4	155	84.2
13	4	119	89.5	5	48	94.0	8	163	88.6
14	3	122	91.6	2	50	98.0	6	169	91.8
15	3	125	94.0	1	51	100.0	4	173	94.0
16	4	129	97.0				3	176	95.6
17	1	130	97.8				4	180	97.8
18	3	133	100.0				1	181	98.4
19							3	184	100.0

TABLE II (CONT'D.)

MICHIGAN-TRUMBULL

m.p.h.	Str. Through Fig. 31 (f')			Str. Through Fig. 31 (h')		
	A	B	C	A	B	C
8	1	1	0.6			
9	1	2	1.6			
10	2	4	2.3			
11	7	11	6.4			
12	14	25	14.5			
13	11	36	20.9			
14	24	60	34.9			
15	18	78	45.3			
16	18	96	55.8			
17	20	116	67.4	3	3	11.5
18	20	136	78.1	0	3	11.5
19	18	154	89.4	0	3	11.5
20	7	161	93.4	0	3	11.5
21	5	166	96.5	3	6	23.1
22	3	169	98.2	2	8	30.7
23	1	170	98.9	1	9	34.6
24	0	170	98.9	3	12	46.1
25	2	172	100.0	0	12	46.1
26				4	16	61.5
27				1	17	65.3
28				5	22	84.5
29				2	24	92.2
30				1	25	96.0
31				0	25	96.0
32				0	25	96.0
33				1	26	100.0

TABLE II (CONT'D.)

MICHIGAN-CASS

m.p.h.	L-Turns Z_2 Fig. 28 (s)			L-Turns Z_{1-2} Fig. 28 (t)			Str. Through Fig. 32 (j')		
	A	B	C	A	B	C	A	B	C
0				1	1	1.7			
1				0	0	1.7			
2	6	6	10.2	1	2	3.3			
3	4	10	17.0	5	7	11.8			
4	5	15	25.4	5	12	20.4			
5	5	20	33.9	5	17	28.8			
6	11	31	52.6	8	25	42.4			
7	7	38	64.4	9	34	57.6			
8	2	40	67.8	7	41	69.5	4	4	18.2
9	3	43	72.9	3	44	74.6	2	6	27.3
10	4	47	79.6	1	45	76.2	5	11	50.0
11	2	49	83.1	3	48	81.3	7	18	81.8
12	2	51	86.5	3	51	86.5	0	18	81.8
13	4	55	93.2	2	53	89.8	3	21	95.5
14	1	56	95.0	4	57	96.6	0	21	95.5
15	2	58	98.4	1	58	98.3	1	22	100.0
16	1	59	100.0	0	58	98.3			
17				0	58	98.3			
18				0	58	98.3			
19				1	59	100.0			

m.p.h.	Str. Through Fig. 32 (k')			Str. Through Fig. 32 (l')		
	A	B	C	A	B	C
8	2	2	2.1			
9	2	4	4.2			
10	1	5	5.2			
11	7	12	12.5			
12	9	21	21.9			
13	13	34	35.4	1	1	2.9
14	14	48	50.1	3	4	11.4
15	10	58	60.4	1	5	14.3
16	13	71	74.0	11	16	45.7
17	7	78	81.2	3	19	54.2
18	7	85	88.6	2	21	60.0
19	3	88	91.6	1	22	62.8
20	2	90	93.8	6	28	80.0
21	2	92	95.8	1	29	82.8
22	3	95	99.0	1	30	85.6
23	1	96	100.0	1	31	88.5
24				1	32	92.4
25				1	33	94.2
26				1	34	97.1
27				1	35	100.0

TABLE II (CONT'D.)

MAIN-HURON

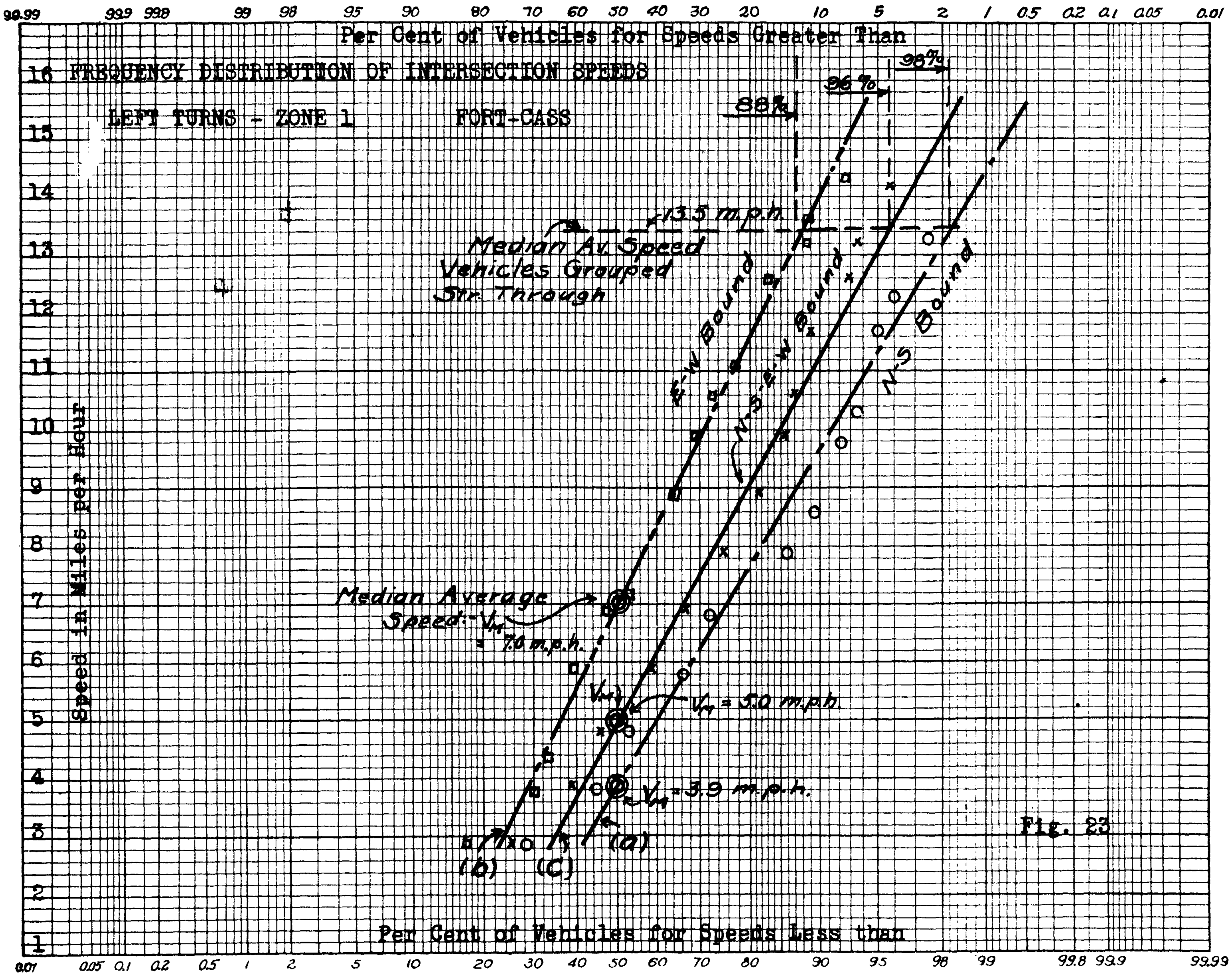
m.p.h.	L-Turns Z_1 Fig. 25 (g)			L-Turns Z_1 Fig. 25 (h)			L-Turns Z_1 Fig. 25 (i)		
	A	B	C	A	B	C	A	B	C
1				1	1	2.9	1	1	1.1
2	4	4	6.8	1	2	5.9	5	6	6.5
3	3	7	11.9	1	3	8.8	4	10	10.8
4	2	9	15.2	0	3	8.8	2	12	12.9
5	5	14	23.8	4	7	20.6	9	21	22.6
6	4	18	30.5	2	9	26.4	6	27	29.0
7	7	25	42.3	5	14	41.2	12	39	42.0
8	9	34	57.6	5	19	56.0	14	53	57.1
9	8	42	71.2	1	20	58.8	9	62	66.7
10	5	47	79.6	8	28	82.4	13	75	80.7
11	4	51	81.4	0	28	82.4	4	79	85.0
12	4	55	93.2	1	29	85.3	5	84	90.3
13	1	56	95.0	3	32	94.1	4	88	94.6
14	2	58	98.2	1	33	97.0	3	91	97.8
15	1	59	100.0	0	33	97.0	1	92	99.0
16				0	33	97.0	0	92	99.0
17				0	33	97.0	0	92	99.0
18				1	34	100.0	0	92	99.0
19							1	93	100.0

m.p.h.	L-Turns Z_{1-2} Fig. 29 (j)			L-Turns Z_{1-2} Fig. 29 (k)			L-Turns Z_{1-2} Fig. 29 (l)		
	A	B	C	A	B	C	A	B	C
1									
2				1	1	2.9	1	1	1.0
3	5	5	8.3	0	1	2.9	5	6	6.3
4	5	10	16.7	2	3	8.6	7	13	13.7
5	3	13	21.7	2	5	14.3	5	18	19.0
6	3	16	26.7	5	10	28.8	8	26	27.4
7	5	21	35.0	2	12	34.3	7	33	34.8
8	10	31	51.7	6	18	51.3	16	49	50.6
9	11	42	70.0	4	22	62.8	15	64	67.3
10	10	52	86.6	6	28	80.0	16	80	84.1
11	3	55	91.7	2	30	85.6	5	85	89.4
12	3	58	96.6	3	33	94.1	6	91	95.7
13	1	59	98.3	0	33	94.1	1	92	96.7
14	1	60	100.0	0	33	94.1	1	93	97.8
15				1	34	97.0	1	94	99.0
16				0	34	97.0	0	94	99.0
17				0	34	97.0	0	94	99.0
18				1	35	100.0	1	95	100.0
19									

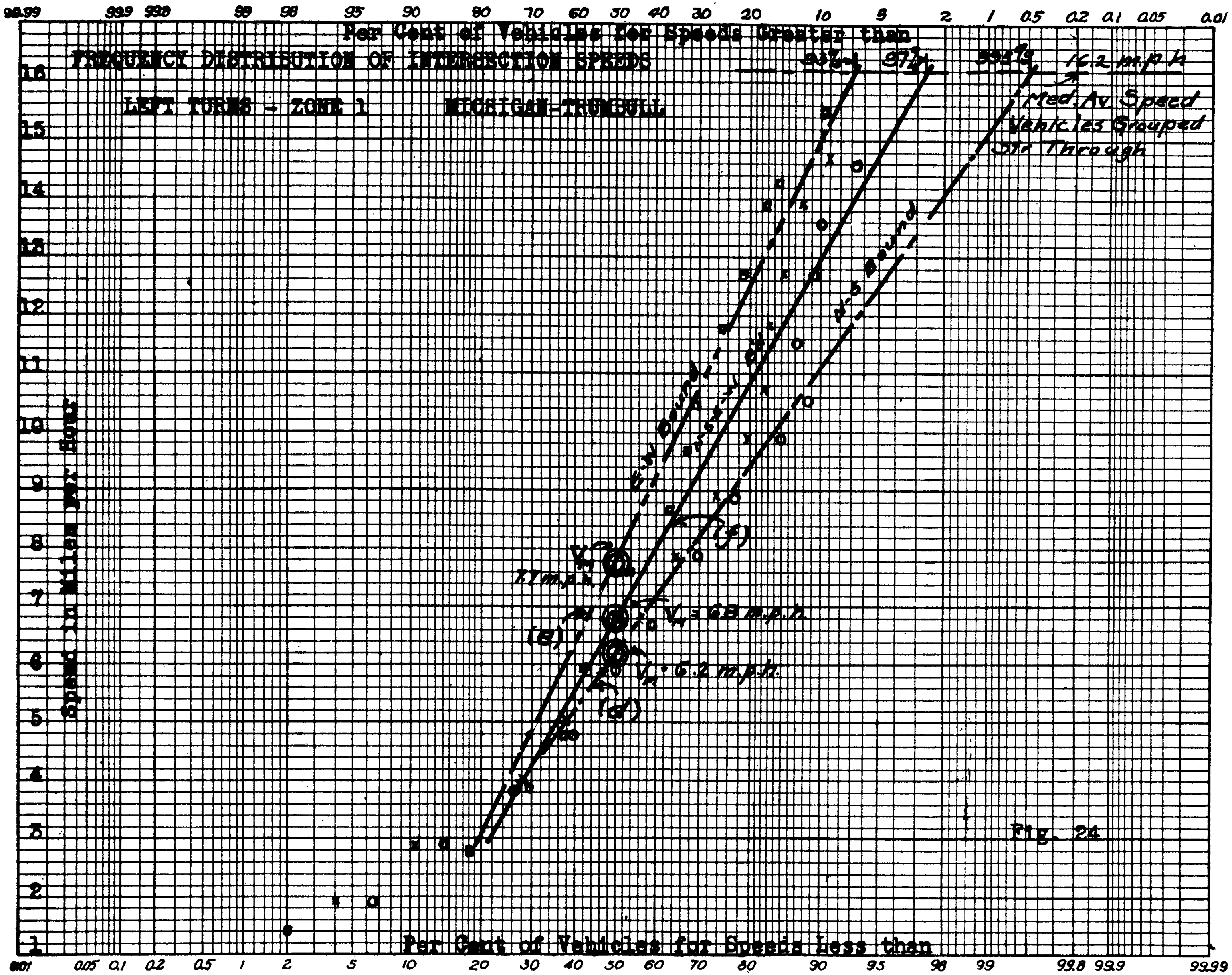
TABLE II (CONT'D.)

MAIN-HURON

m.p.h.	Str. Through Fig. 33 (a') A	B	C	Str. Through Fig. 33(b') A	B	C
7	8	8	25.8			
8	8	16	51.6	1	1	1.8
9	7	23	74.2	4	5	8.9
10	4	27	87.2	6	11	19.6
11	3	30	96.8	8	19	33.9
12	0	30	96.8	13	32	57.1
13	1	31	100.0	7	39	69.6
14				4	43	76.7
15				2	45	80.3
16				8	53	94.6
17				2	55	98.1
18				0	55	98.1
19				1	56	100.0

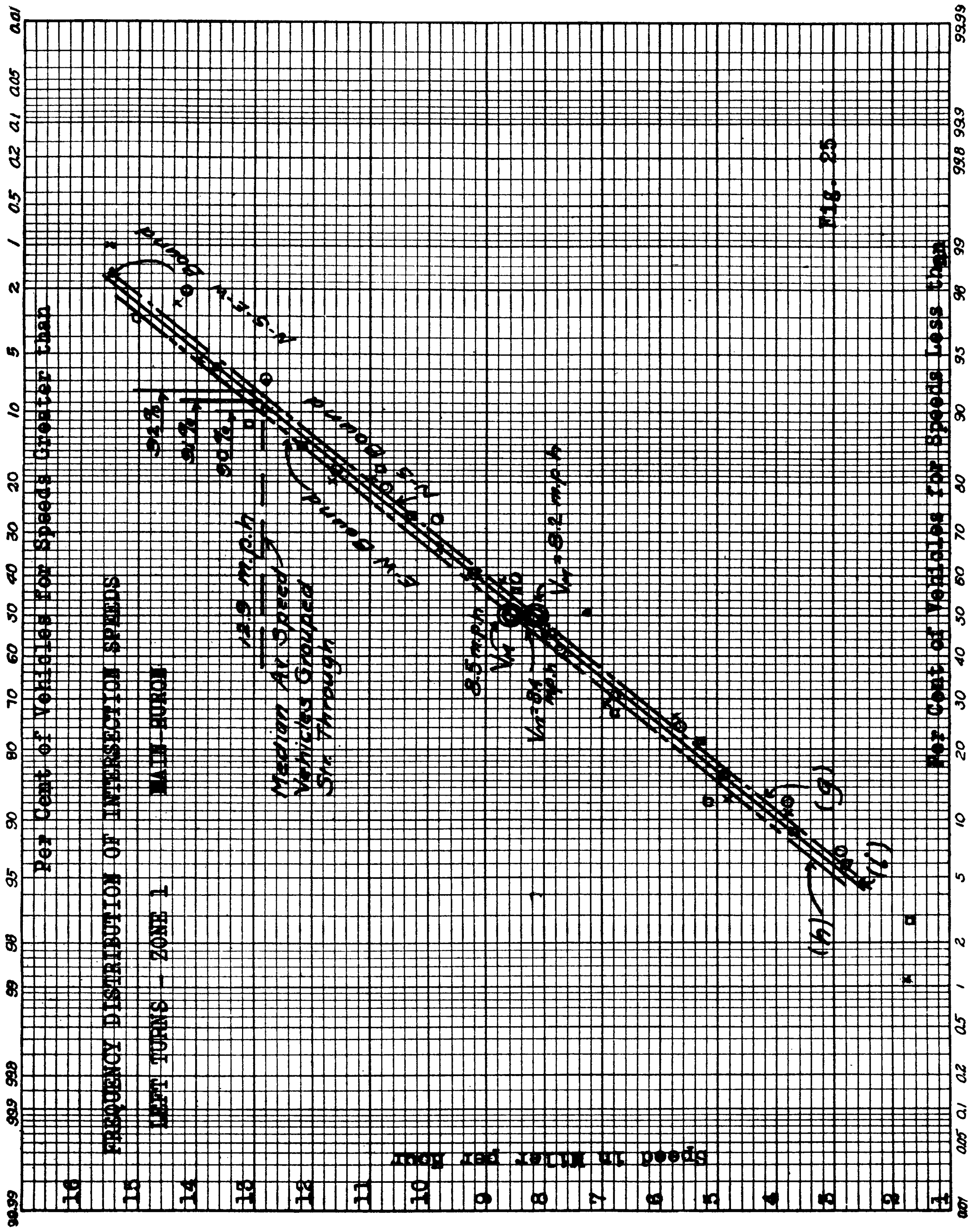


Per Cent of Vehicles for Speeds Greater Than
FREQUENCY DISTRIBUTION OF INTERSECTION SPEEDS
LEFT TURNS - ZONE 1
FORT-CASS
88%
96%
98%
13.5 m.p.h.
Median Av. Speed
Vehicles Grouped
Str. Through
E-W Bound
N-S-E-W Bound
N-S Bound
Median Average
Speed-V_M
= 7.0 m.p.h.
V_M = 5.0 m.p.h.
V_M = 3.9 m.p.h.
(a)
(b)
(C)
Fig. 23
Speed in Miles per Hour
Per Cent of Vehicles for Speeds Less than

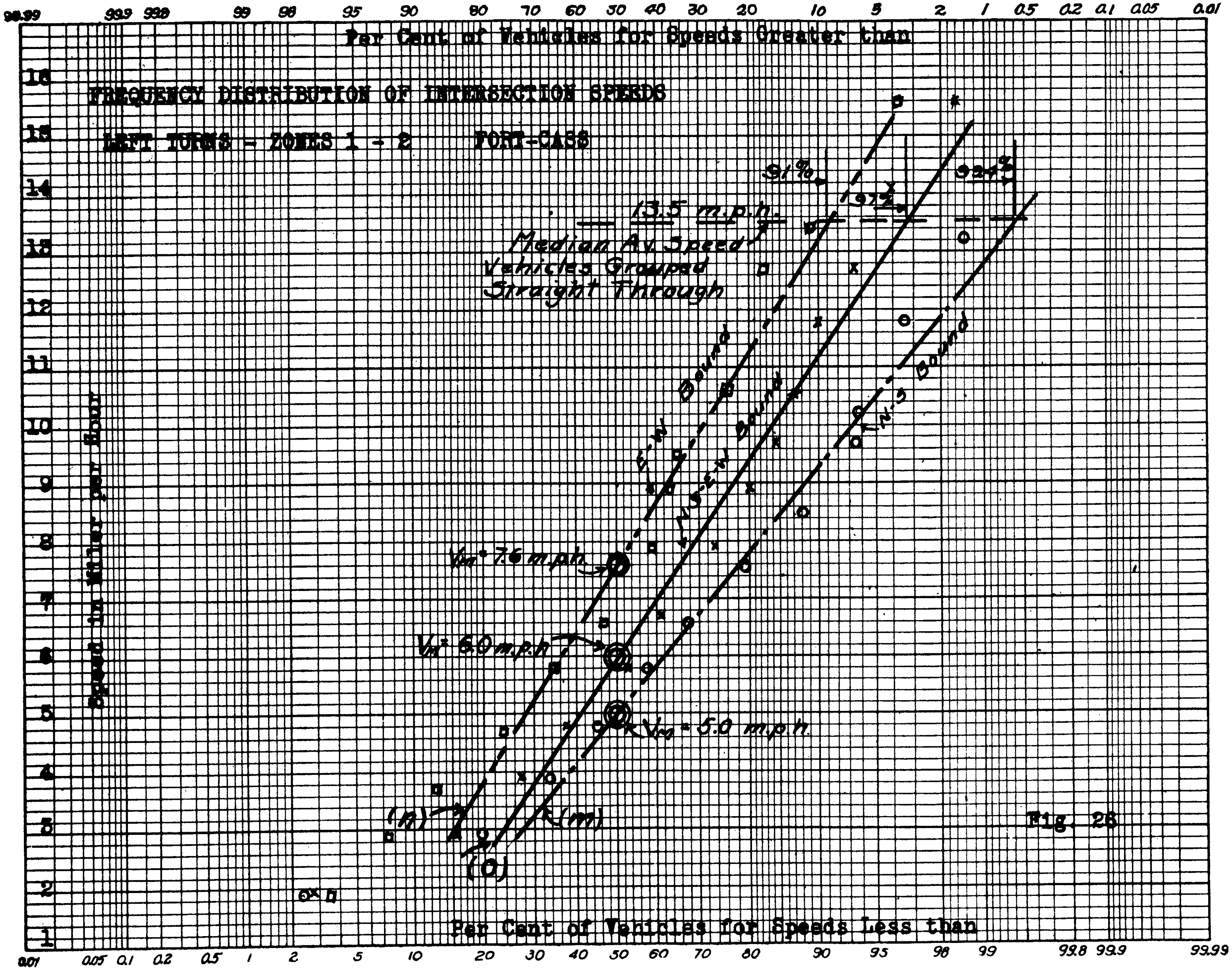


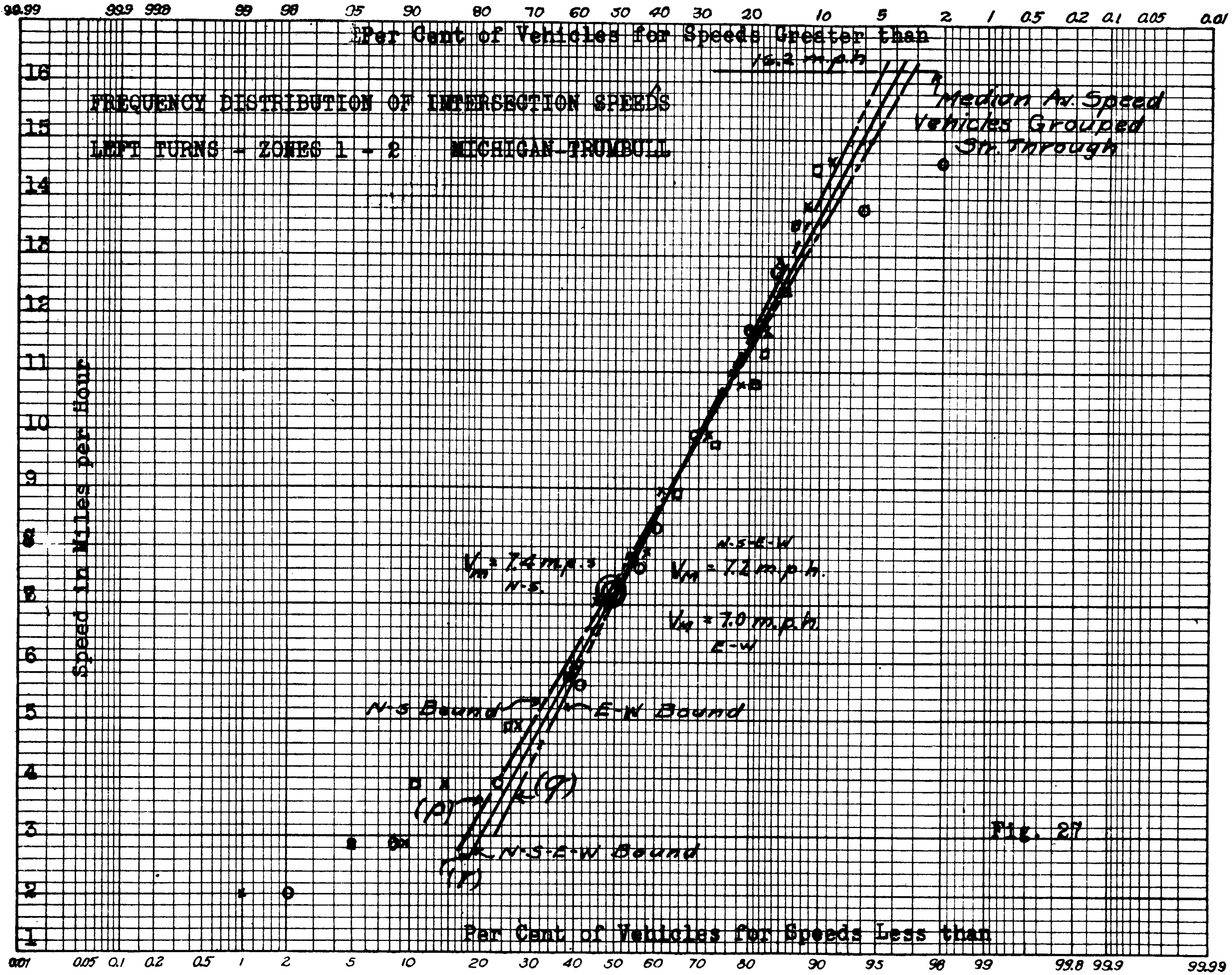
Per Cent of Vehicles for Speeds Greater than
FREQUENCY DISTRIBUTION OF INTERSECTION SPEEDS
LEFT TURNS - ZONE 1
MICHIGAN-TRUMBULL
16.2 m.p.h
Med. Av. Speed
Vehicles Grouped
for Through
E-W Bound
N-S Bound
Speed in Miles per Hour
7.7 m.p.h
V_m = 6.8 m.p.h
V_m = 6.2 m.p.h.
(e)
(f)
(d)
Per Cent of Vehicles for Speeds Less than

Fig. 24



Per Cent of Vehicles for Speeds Greater than
FREQUENCY DISTRIBUTION OF INTERSECTION SPEEDS
LEFT TURNS - ZONE 1
MAIN-HURON
Median Av Speed
Vehicles Grouped
Str Through
12.9 m.p.h
8.5 m.p.h
Vr = 8.2 m.p.h
Speed in Miles per Hour
Per Cent of Vehicles for Speeds Less than
Fig. 25


FREQUENCY DISTRIBUTION OF INTERSECTION SPEEDS
LEFT TURNS - ZONES 1 - 2 FORT-CASS
Per Cent of Vehicles for Speeds Greater than
Per Cent of Vehicles for Speeds Less than
Speed in Miles per Hour
13.5 m.p.h.
Median Av. Speed
Vehicles Grouped
Straight Through
91%
97%
92%
E-W Bound
NS-EW Bound
N-S Bound
Vm = 7.6 m.p.h.
Vm = 6.0 m.p.h.
Vm = 5.0 m.p.h.
(n)
(m)
(o)
Fig. 28



Per Cent of Vehicles for Speeds Greater than
16.2 m.p.h.
FREQUENCY DISTRIBUTION OF INTERSECTION SPEEDS
LEFT TURNS - ZONES 1 - 2 MICHIGAN-TRUMBULL
Median Av. Speed
Vehicles Grouped
Str. Through
Speed in Miles per Hour
Vm = 7.4 m.p.h. N-S
Vm = 7.2 m.p.h. N-S-E-W
Vm = 7.0 m.p.h. E-W
N-S Bound
E-W Bound
N-S-E-W Bound
(p)
(q)
(r)
Fig. 27
Per Cent of Vehicles for Speeds Less than

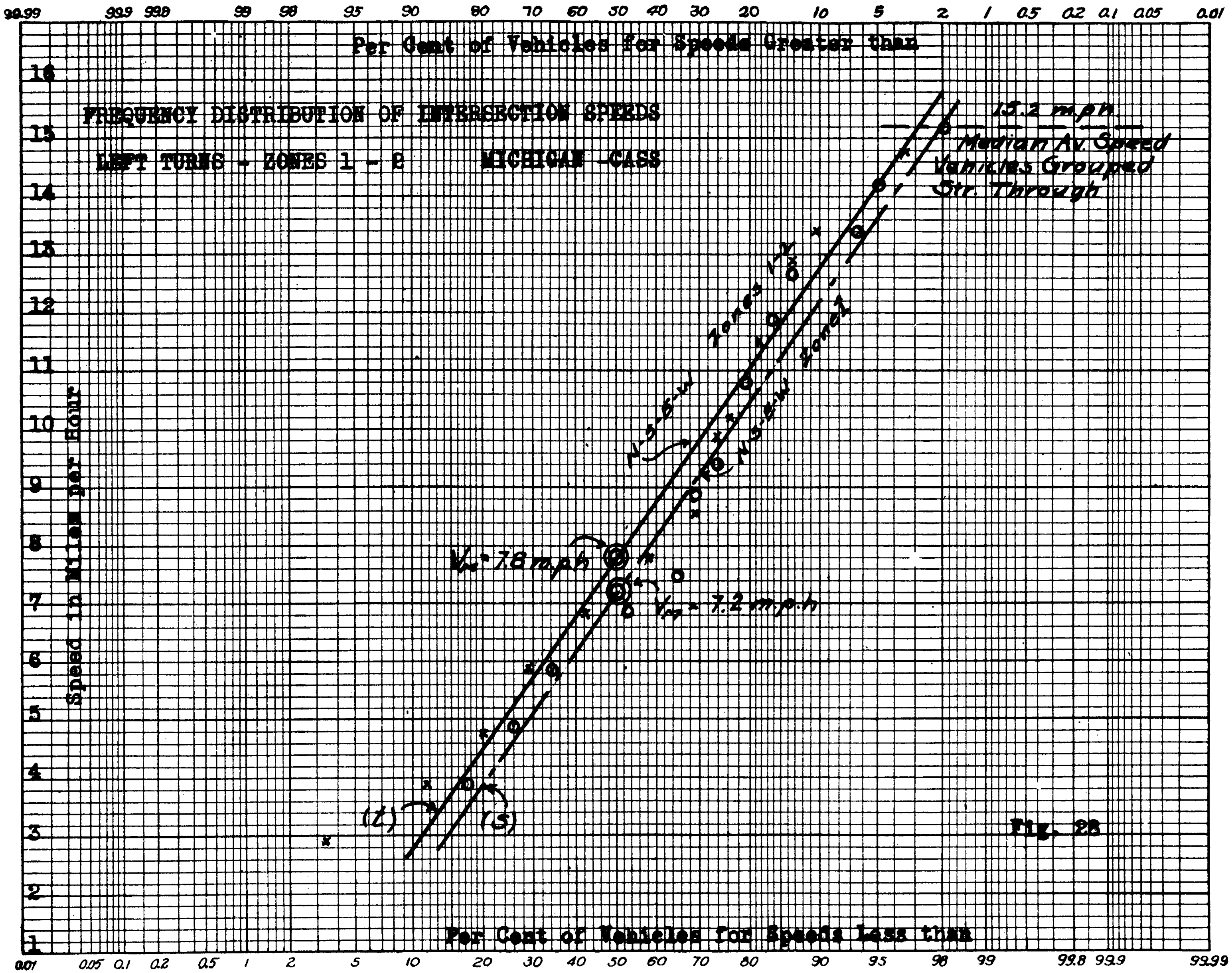
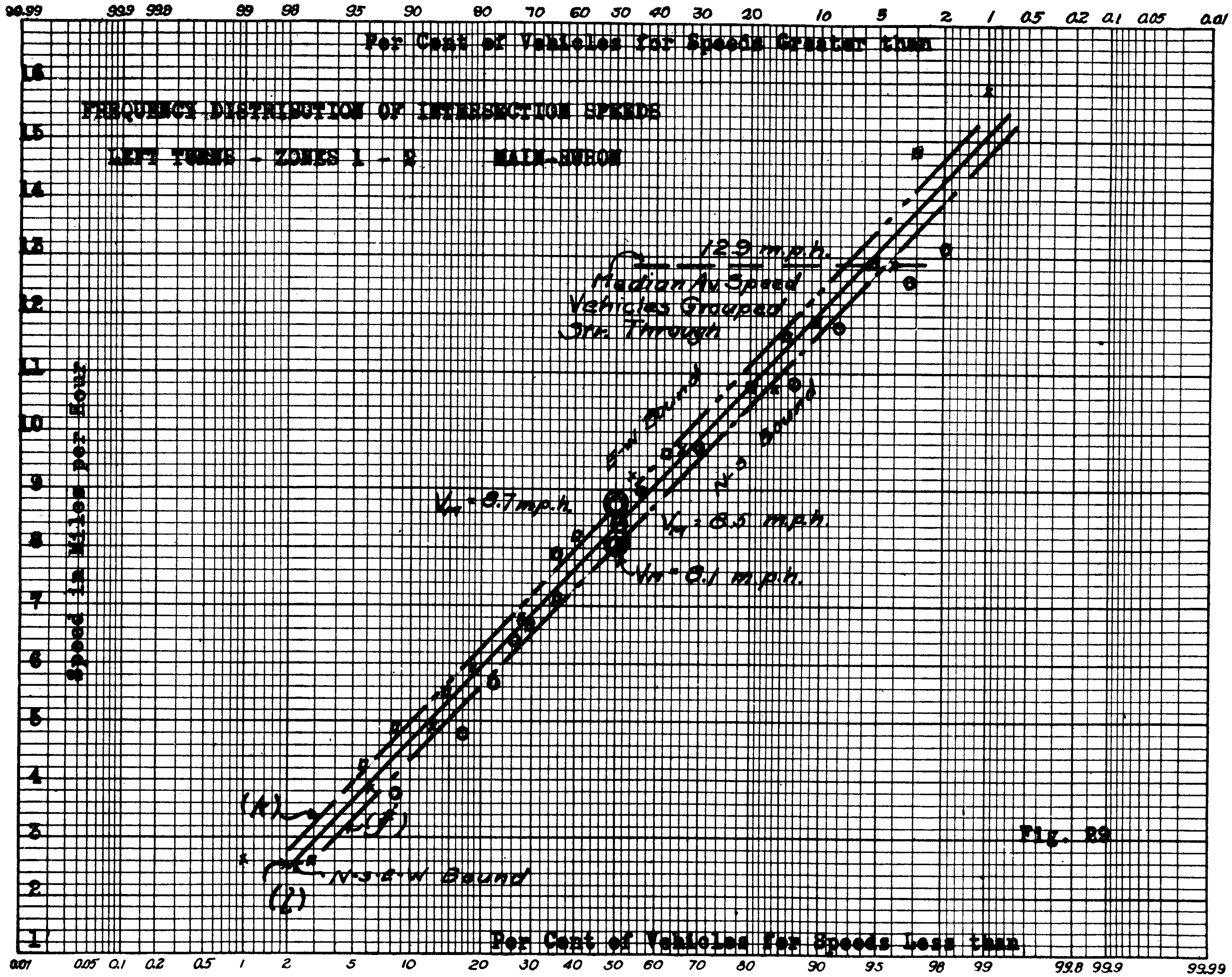

Per Cent of Vehicles for Speeds Greater than
FREQUENCY DISTRIBUTION OF INTERSECTION SPEEDS
LEFT TURNS - ZONES 1 - 2 MICHIGAN - CASS
15.2 m.p.h.
Median Av. Speed
Vehicles Grouped
Str. Through
Zones 1-2
Zone 1
N-S-E-W
N-S-E-W
V_m = 7.8 m.p.h.
V_m = 7.2 m.p.h.
(t)
(s)
Speed in Miles per Hour
Per Cent of Vehicles for Speeds Less than

Fig. 28


Per Cent of Vehicles for Speeds Greater than
FREQUENCY DISTRIBUTION OF INTERSECTION SPEEDS
LEFT TURNS - ZONES 1 - 2   MAIN-HURON
Speed in Miles per Hour
12.9 m.p.h.
Median Av. Speed
Vehicles Grouped
Str. Through
E-W Bound
N-S Bound
V_m = 8.7 m.p.h.
V_m = 8.5 m.p.h.
V_m = 8.1 m.p.h.
(k)
(f)
(l)
N-S & W Bound
Per Cent of Vehicles for Speeds Less than
Fig. R9

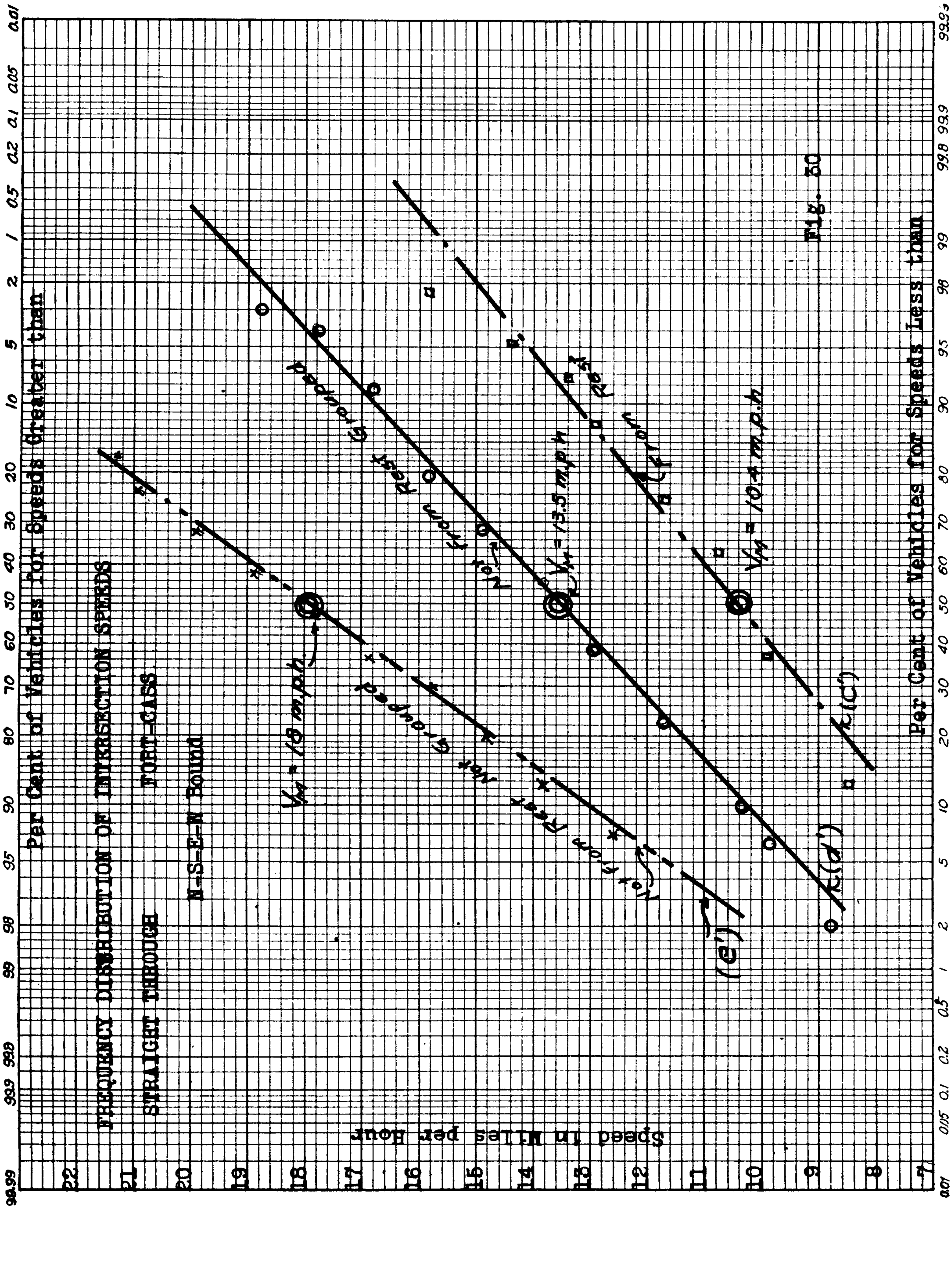

FREQUENCY DISTRIBUTION OF INTERSECTION SPEEDS
STRAIGHT THROUGH
FORT-CASS
N-S-E-W Bound
Per Cent of Vehicles for Speeds Greater than
Per Cent of Vehicles for Speeds Less than
Speed in Miles per Hour
V_m = 18 m.p.h.
V_m = 13.5 m.p.h
V_m = 10.4 m.p.h
(c')
(d')
(e')

Fig. 30

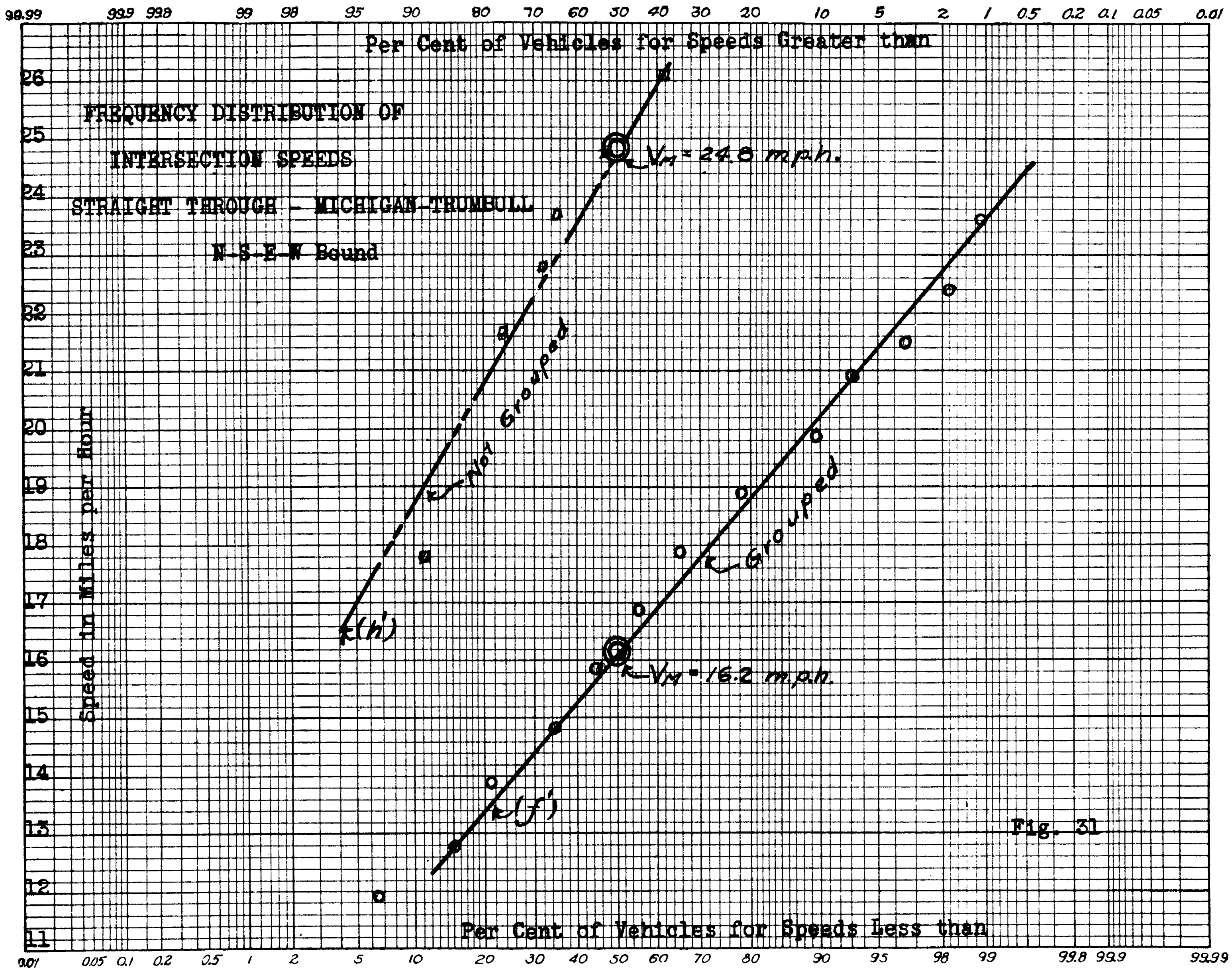
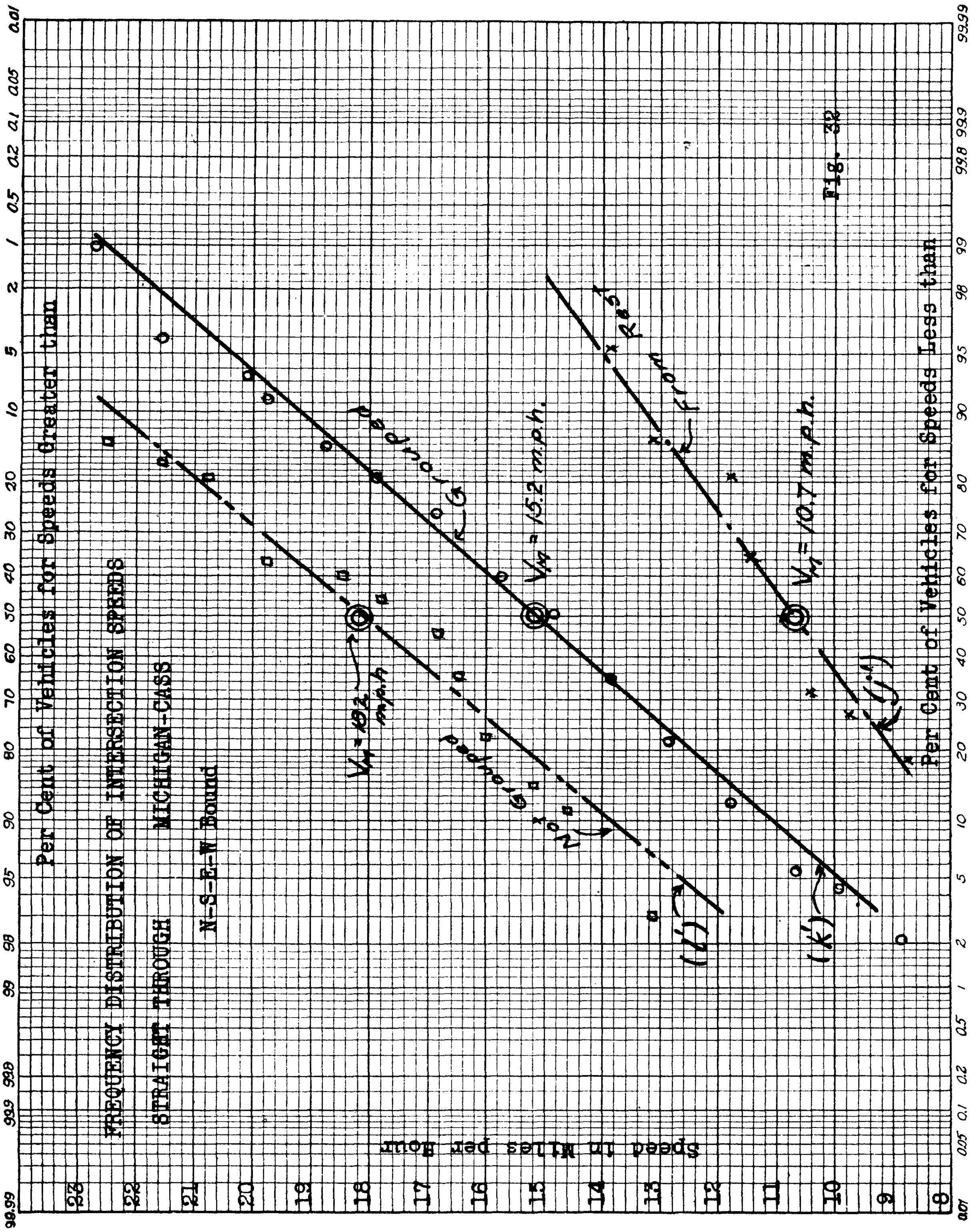

Per Cent of Vehicles for Speeds Greater than
FREQUENCY DISTRIBUTION OF
INTERSECTION SPEEDS
STRAIGHT THROUGH - MICHIGAN-TRUMBULL
N-S-E-W Bound
V_M = 24.8 m.p.h.
V_M = 16.2 m.p.h.
Not Grouped
Grouped
(h')
(f')
Speed in Miles per Hour
Per Cent of Vehicles for Speeds Less than
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99
26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11

Fig. 31


Per Cent of Vehicles for Speeds Greater than
FREQUENCY DISTRIBUTION OF INTERSECTION SPEEDS
STRAIGHT THROUGH MICHIGAN-CASS
N-S-E-W Bound
Speed in Miles per Hour
Per Cent of Vehicles for Speeds Less than
Fig. 32
V_M = 15.2 m.p.h.
V_M = 10.7 m.p.h.
V_M = 18.2 m.p.h.
(k')
(l')

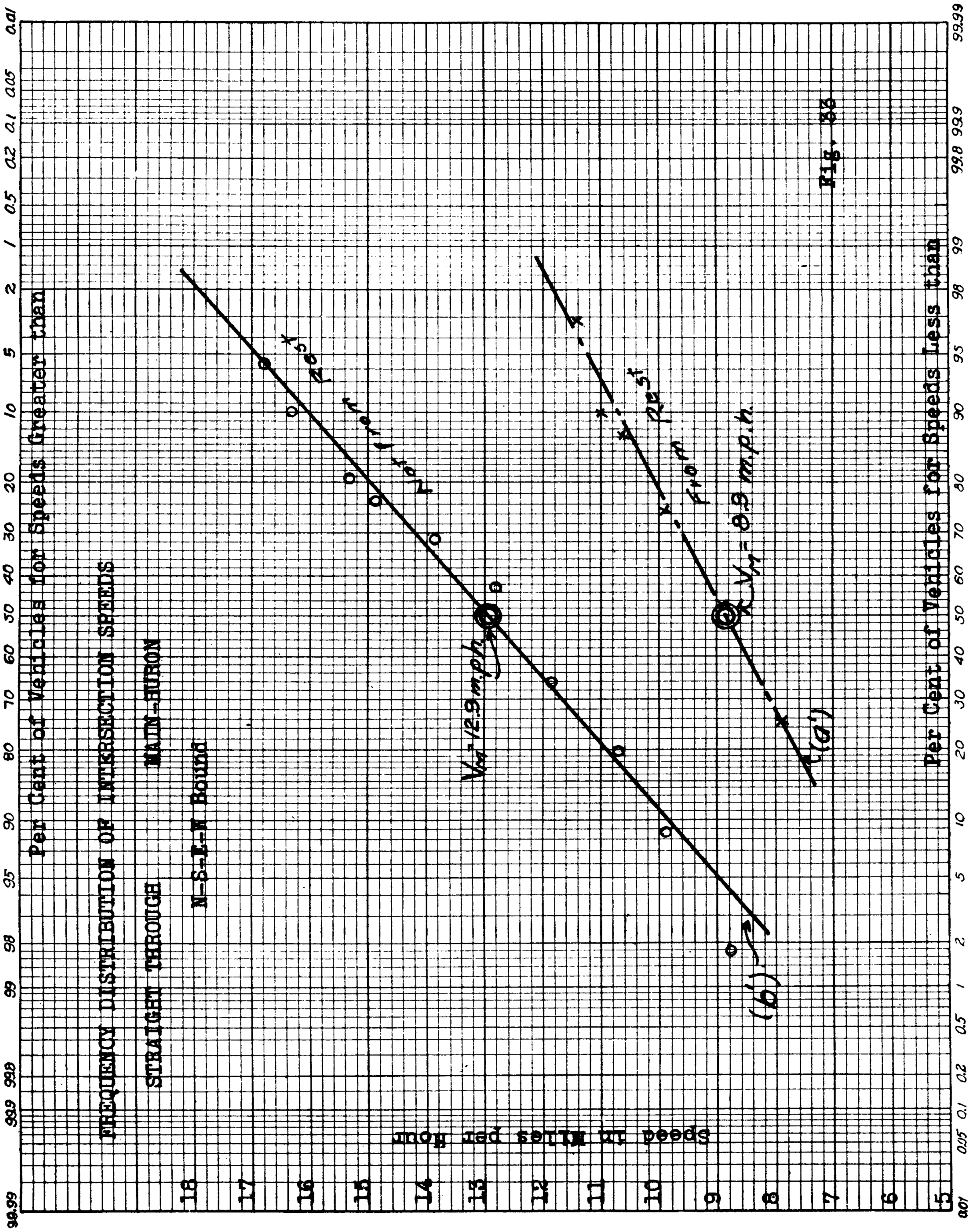

Per Cent of Vehicles for Speeds Greater than
FREQUENCY DISTRIBUTION OF INTERSECTION SPEEDS
STRAIGHT THROUGH MAIN-HURON
N-S-E-W Bound
Not from rest
From rest
Vs=12.9 m.p.h.
Vr=8.9 m.p.h.
(b')
(a')
Speed in Miles per Hour
Per Cent of Vehicles for Speeds Less than

Fig. 33

SUMMARY OF INTERSECTION SPEEDS

The speed values as observed at all four intersections under different conditions, both for turning vehicles and for those going straight through, are combined in Table III. A study of this table shows that the median averages for practically all instances are less than the arithmetical mean averages, thus following the general rule for the relation between these two types of averages. As these former values are usually more representative of the true averages, they will be used for comparison. Of the vehicles passing straight through the intersection, those not starting from rest and moving in groups were chosen for comparison, since the vehicles starting from rest would include only the first one at the beginning of the waiting line, and these would not be delayed by any turning vehicle; and the vehicles not moving in groups represent very light traffic flow, which condition has a less appreciable influence upon the free movement of the rest of the vehicles in the intersection, and consequently on the proper timing of the signal lights to provide for the volume of traffic in question.

After the data thus far considered had been assembled, it became apparent that further information bearing upon the following points was desirable:

(a) Actual volume counts of vehicles during the time of observation.

(b) Lane distribution of moving traffic, or the number of vehicles using the inner and outer lanes, respectively. Values for both (a) and (b) are to be found in Table IV.

(c) Nature of the turning movements, classifying vehicles as those delayed alone, those causing delay, those delayed in groups, and those not delayed. The method of collecting this data is shown in Exhibit E. The summary results for all four intersections are given in Table V; and Figure 34.

TRAFFIC FLOW IN INNER AND OUTER LANES

The data for (a) and (b) of the above enumeration are summarized in Table IV where the traffic per lane is indicated in volume and in per cent. This classification held for the three intersections in Detroit where at least two lanes were available for all directions of travel. The

TABLE III

SUMMARY SHEET OF SPEED AVERAGES

	Mean Averages m.p.h.				Median Averages m.p.h.			
	Main-Huron	Michigan-Trumbull	Fort-Cass	Michigan-Cass	Main-Huron	Michigan-Trumbull	Fort-Cass	Michigan-Cass
LEFT TURNS								
Z_1								
N.S. Bound	8.4	6.9	5.2		8.2	6.2	3.9	
E.W. Bound	8.9	8.0	7.9		8.5	7.7	7.0	
N.S-E.W. Bound	8.6	7.2	6.0	7.8	8.4	6.8	5.0	7.2
Z_1 & Z_2								
N.S. Bound	8.4	8.2	5.7		8.1	7.4	5.0	
E.W. Bound	9.0	7.8	7.9		8.7	7.0	7.6	
N.S-E.W. Bound	8.6	8.1	6.4	8.1	8.5	7.2	6.0	7.8
STRAIGHT THROUGH								
From Rest	9.2	9.7	10.7	11.0	8.9	9.4	10.4	10.7
Not From Rest Grouped	13.0	16.4	14.0	15.3	12.9	16.2	13.5	15.2
Not Grouped		25.2	19.2	18.7		25.2	18.0	18.2
Traffic Volume v.p.h.	1180	2040	2480	2040	1180	2040	2480	2040

intersection at Main and Huron, Ann Arbor, provided only one moving lane in each direction.

A study of this data shows that in the case of the three intersections considered, the distribution of traffic in the different lanes is approximately fifty per cent for each lane. These results will be useful in a later discussion relative to the determination of the critical lane for traffic volume count as one of the factors entering into the equation for cycle length.

DETERMINATION OF THE DELAYING INFLUENCE OF LEFT-TURNING VEHICLES

Exhibit E is an example of the data sheet used to record the movement of left-turning vehicles.

Table V is the summary data sheet for these different groups of left-turning vehicles. The first line for each street gives the number of left-turning vehicles for the different directions; the second line, the total for all directions in each group; and the third line, the per cent. The percentage values are plotted in Figure 34, including a set of diagrams,for each intersection, as well as one for the totals for the three intersections of Detroit showing a common characteristic that will be explained in the following paragraph.

From a study of Figure 34, which classifies the left-turning vehicles into four groups - those delayed alone, those causing delay, those delayed in groups, and those not delayed - the following relationships are seen to exist.

For the three intersections at Fort-Cass, Michigan-Cass, and Michigan-Trumbull, where the traffic volume exceeded two thousand V.P.H., the per cent of left-turning vehicles in the different groups appears quite uniform. The vehicles of the first and last groups evidently do not cause any delay to the other vehicles in the same lane, and moving in the same direction. As seen from the fifth set of diagrams covering the first three intersections, the per cent of non-delaying turning vehicles amounts to (13 8) 21 per cent of all of the left-turning vehicles.

The per cents listed in Column 2 - Figure 34 - represent those turning vehicles which headed the waiting line, and which were therefore the direct cause of actual delay to the vehicles following. Column 3 - delayed in groups - represents the vehicles forming part of the waiting line.

TABLE IV

VOLUME COUNT - LANE DISTRIBUTION

	N-Bound Inside Lane		Outside Lane		S-Bound				E-Bound				W-Bound				Totals		
	i	%	o	%	i	%	o	%	i	%	o	%	i	%	o	%	No.of Veh.	Time in Min.	Veh. per Hr.
Fort-Cass 2000 Pictures	166	68	79	32	196	53	177	47	243	44	313	56	138	38	228	62	1540	37	2480
					Total in inner lane i= 743 -- 48%														
					Total in outer lane o= 797 -- 52%														
Michigan Trumbull 4000 Pcitures	213	41	302	59	236	46	277	54	443	49	458	51	519	51	257	49	2938	86	2040
											i = 1411 -- 48%								
											o = 1527 -- 52%								
Michigan-Cass 1100 Pictures	111	65	59	35	125	66	64	34	50	50	51	50	67	46	77	54	604	18	2040
											i = 353 -- 58%								
											o = 251 -- 42%								
Main-Huron 2000 Pictures	158 (Single Lane)				158				178				178				672	34	1180

Totals for 3 multiple - lane intersections
i = 2507 -- 49%
o = 2575 -- 51%

DATA SHEET FOR LEFT-TURNING VEHICLES

N-S Bound — Michigan-Trumbull

	Cycles	Delayed Alone	Causing Delay	Delayed in Group	Not Delayed	Total
N-Bound	1		//			//
	2					
	3					
	4				/	/
	5		/		/	//
	6		/		//	///
	7		/	/		//
	8	/			/	//
	9		//	/		///
	10		/	/		//
	11			/		/
	12	/	/			//
	13	/	//			///
	14				/	/
	15		/			/
		3	12	4	6	25
S-Bound	1	/	/	//		////
	2		/		/	//
	3		/	//		///
	4	/				/
	5		/	/		//
	6			/	/	//
	7		//		/	///
	8		/	/		//
	9	/		/		//
	10		/		/	//
	11	/	//	/		////
	12		/	/		//
	13		/			/
	14	/				/
	15		/	/		//
		5	13	11	4	33

Exhibit E

LEFT-TURNING VEHICLES

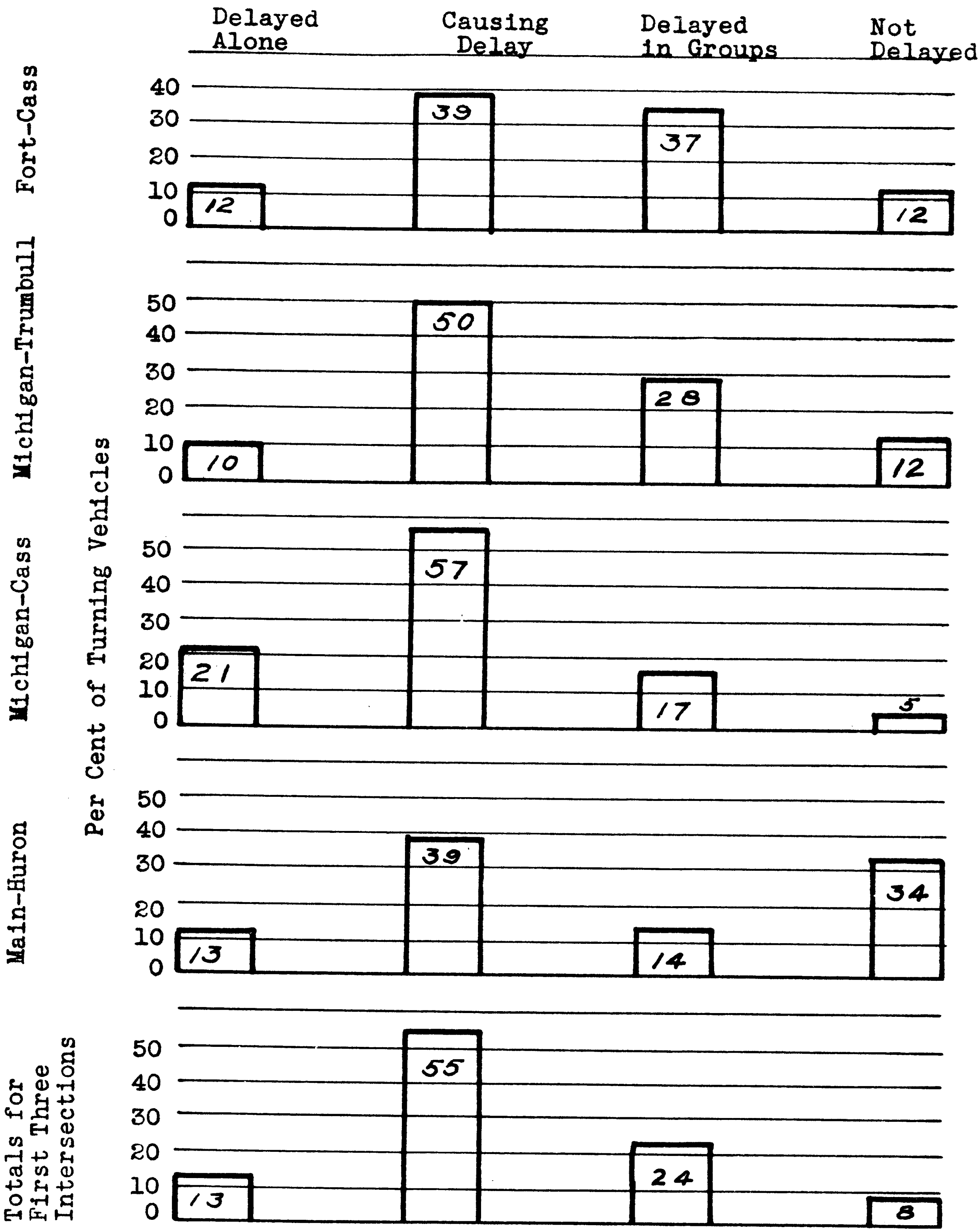


Figure 34

TABLE V

LEFT-TURNING VEHICLES

	Delayed Alone				Causing Delay				Delayed in Groups				Not Delayed				Totals
	N	S	E	W	N	S	E	W	N	S	E	W	N	S	E	W	
Fort-Cass	5	6	10	0	18	31	18	2	13	35	14	1	2	8	12	0	175
Total		21				69				63				22			
Per Cent		12				39				37				12			
Michigan-Trumbull	14	12	2	2	19	47	26	3	6	36	14	0	11	9	5	0	196
Total		20				95				56				25			
Per Cent		10				50				28				12			
Michigan-Cass	4	5	2	2	14	17	1	2	3	7	0	0	3	0	0	0	60
Total		13				34				10				3			
Per Cent		21				57				17				5			
Main-Huron	5	2	2	3	9	10	5	11	3	4	3	3	15	8	2	5	90
Total		12				35				13				30			521
Per Cent		13				39				14				34			
First Three Intersections Totals		43				186				82				29			
Per Cent		13				55				24				8			

Though not being a direct cause of delay, as in the case of the preceding group, they might still be considered as having a delaying influence upon the traffic movement through the intersection.

This same relation does not obtain for the intersection at Main-Huron. This can be explained from the fact that with a traffic flow that is considerably less in V.P.H. (1180), the number of undelayed turning vehicles would be proportionately larger -- in this case, thirty-four per cent, as compared with the values twelve, twelve and five, for the other intersections.

These relationships as found to exist between the total volume of traffic passing the intersection and the per cent of left-turning vehicles that actually exert a delaying influence on the vehicular movement in the intersection, suggest that when considering the turning vehicles in determining the cycle length, this distinction between delaying,and non-delaying left-turning vehicles should be made. This has been done by multiplying the expression given in equation (8) by the "Reduction Factor" k.

In the absence of further factual data that would form the basis for the construction of a graduated scale to show this relationship, the data as found in Figure 34 will be used to arrive at the following values for k:

TABLE VI

Vehicles per Hour passing the Intersection	Value of Reduction Factor k in Per Cent.
2000 or more	75
Less than 2000	50

RELATIONSHIP BETWEEN SPEED OF LEFT-TURNING VEHICLES AND TRAFFIC VOLUME

Figure 35, sets forth the relation found to exist between the average median speeds of left-turning vehicles and the volume of traffic passing through the intersection.

The fact that the curve is the result of but four points taken from data at the four intersections investigated, justification for definite conclusions might be questioned. On the other hand, the diagram may be accepted as having some significance, due to the fact that the values representing the average speeds of left-turning vehicles were obtained from the analysis of nine thousand pictures for the four intersections, and of five hundred and twenty left-turning vehicles.

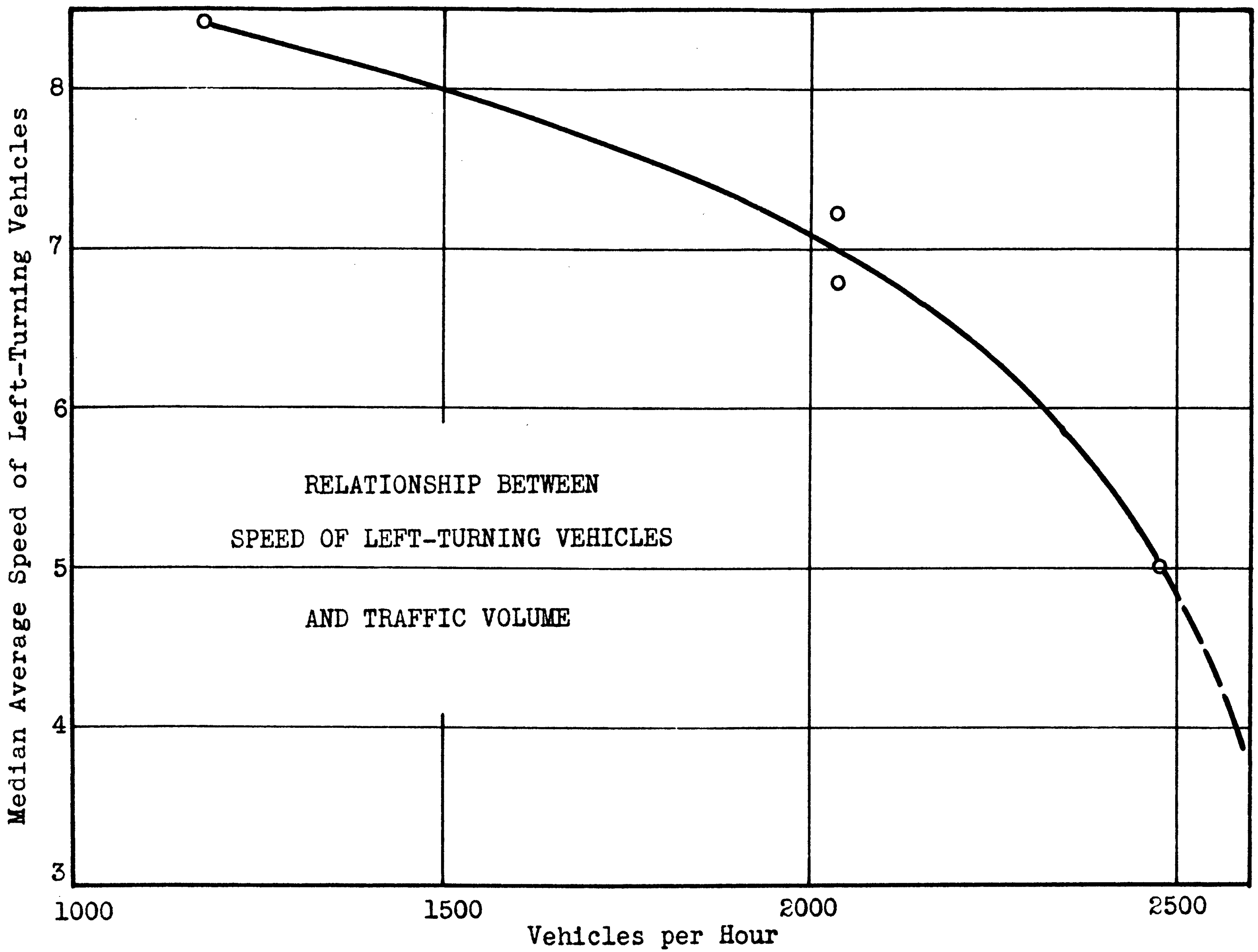

RELATIONSHIP BETWEEN
SPEED OF LEFT-TURNING VEHICLES
AND TRAFFIC VOLUME
Median Average Speed of Left-Turning Vehicles
8
7
6
5
4
3
1000
1500
2000
2500
Vehicles per Hour

Fig. 35

That the trend as shown by the curve might be considered logical, is borne out by a close study of the pictures observed. As the traffic, especially that moving in a direction opposite to that from which the turning vehicles are coming, increases, there is less possibility of the latter to cut through. And it can readily be seen that when this flow reaches a certain volume, the delay would continue to increase, approaching a condition of deadlock for the traffic in the center lanes. This is indicated by the rather sudden drop of the curve when the volume of traffic flow gets beyond two thousand V.P.H. As no observations were made at any intersection with a volume count exceeding twenty-five hundred V.P.H., the broken line merely indicates a possible trend.

FORMULAS FOR CYCLE LENGTH IN TRAFFIC SIGNAL TIMING

Of the formulas that have been developed pertaining to cycle length and cycle distribution, two will be discussed in the following pages.

The first of these was advanced by Earl J. Reeder, Traffic Engineer of the National Safety Council, and published in Public Safety Memo, No. 84, May, 1932. The development of the equation followed the method used by J. S. Baker of the National Safety Council, in deriving a similar formula which was published in Public Safety of June, 1931. But subsequent observations necessitated the revision of some of the assumptions used in the latter. The later equation of Reeder will be used in the discussion that follows:

The other formula was presented by Carl P. Nachod, Vice-President of the Nachod and U. S. Signal Corporation, Inc., at the Fifth Annual Meeting of the Institute of Traffic Engineers in 1934, and published in the Proceedings of the Institute of that year.

In the discussion that follows, both of these formulas will be presented in their original form, and will then be revised to take into consideration the delay and consequent time loss occasioned by left-turning vehicles. The experimental data for this latter aspect of the problem has been obtained from the investigation carried out by the author, as described in the preceding portion of the present chapter.

Discussion of Formula for Cycle Length by E. J. Reeder

Case I -- Assuming no Left Turns.

In the first of these formulas the following symbols are used.

n' -- the number of vehicles crossing the intersection from one direction during the peak five minute period (Not limited to single lane).

n'' -- the same for vehicles on the other street.

s' and s'' -- the time spacing of vehicles in seconds as they leave the intersection corresponding to n' and n''.

v' and v'' -- average speed in m.p.h. of vehicles leaving the intersection, corresponding to traffic flow n' and n''.

y -- yellow interval for each direction.

t -- cycle length in seconds.

g -- length of green interval in seconds.

(1) $\frac{n'}{300} =$ the number of vehicles passing per second.

(2) $\frac{n'\ t}{300} =$ number of vehicles per cycle $\underline{t}$.

(3) $\frac{n'\ t\ s'}{300} = 0.0033\ n'\ s'\ t$

$=$ time required to pass these vehicles through the intersection at average speed, and spacing of s' seconds.

$\frac{v}{2a}$ delay caused by acceleration of vehicles; assuming $a = 2.5$ m.p.h.p.s.

$= 0.2\ v$ ... acceleration loss.

Then

(4) $g' = 0.0033\ n'\ s'\ t + 0.2\ v' + y$

(5) $g'' = 0.0033\ n''\ s''\ t + 0.2\ v'' + y$

(6) $t = g' + g''$

$= 0.0033\ n'\ s'\ t + 0.2\ v' + y + 0.0033\ n''\ s''\ t + 0.2\ v'' + y$

Solving for $\underline{t}$

$$t = \frac{0.2\ (v' + v'') + 2y}{1 - 0.0033\ (n's' + n''s'')} \qquad \text{EQUATION I}$$

Case II - Including Left Turns

The following discussion takes up the case where left-turning vehicles are actually present and affecting the free movement of traffic passing through the intersection.

Although the terms "n" and "s" in Equation I, were not confined to single lane traffic, the following application of the formula is based on the assumption of but one traffic lane. This equation will be revised by adding the factors obtained from the investigation of left-turning vehicles as referred to above.

The following symbols will be used in addition to those found in Equation I;-

p' -- p'' -- ratio of left-turning vehicles to total traffic, in per cent, corresponding to n' and n''

v'_t -- v''_t -- average speed of left-turning vehicles whilst passing through Zone 1 (Zone of Influence)

d -- distance from beginning of intersection - at outer edge of crosswalk - to center of intersection; assumed to be the average distance travelled by the left-turning vehicles in passing through Zone 1.

k -- the per cent of left-turning vehicles actually causing delay.

Note:

In Equation 1, v' & v'' represented the average speed of vehicles leaving the intersection; but the average speed of vehicles passing through the intersection is here considered the same as v' & v'' as defined above, since this average speed through the intersection determines the capacity of the intersection.

$\frac{d'}{v'}$ -- time of travel of through traffic in one direction when passing from point of entrance of intersection to the center of intersection.

$\frac{d'}{v'_t}$ -- time required by left-turning vehicles to pass through Zone 1; the distance travelled by the turning vehicles was assumed to be approximately equal to the distance, d; analysis of more than five hundred turning vehicles observed in the investigation appears to justify this assumption.

$\frac{d'}{v'_t} - \frac{d'}{v'} =$ time loss, in seconds, caused by <u>one</u> left-turning vehicle.

$$= d' \left(\frac{1}{v'_t} - \frac{1}{v'}\right) = d' \frac{(v'-v'_t)}{v' \; v'_t}$$

From Equation (2)
0.0033 n't -- is the number of vehicles per cycle.
Therefore,

(8) 0.0033 kp'n't is the number of <u>left-turning</u> vehicles in one cycle in one direction actually causing delay.

and

(9) $0.0033 \, kp'n'td' \frac{(v'-v'_t)}{v'_t \; v'}$ -- is the total time loss caused by this number of turning vehicles.

Adding this factor for both streets to Equations (4), (5) and (6), we have the following:

(10) $$g' = 0.0033 \, n's't + 0.2 \, v' + y + 0.0033 \, k \, p'n'td' \frac{(v'-v')}{v'_t \; v''}$$

(11) $$g'' = 0.0033 \, n''s'' \, t + 0.2 \, v' + y + 0.0033 \, kp''n''td'' \frac{(v''-v''_t)}{v''_t \; v''}$$

Then

$$t = g' + g''$$

(12) $$= 0.0033t \left(s'n' + s''n'' + kp'n'd' \frac{(v'-v'_t)}{v'_t \; v'} + kp''n''d'' \frac{(v''-v''_t)}{v''_t \; v''} \right) + 0.2 \, (v'+v'') + 2y$$

Solving for <u>t</u>

$$t = \frac{0.2(v'+v'')+2y}{1 - 0.0033 \left(s'n'+s''n''+kp'n'd' \frac{(v'-v'_t)}{v'_t \; v'} + kp''n''d'' \frac{(v''-v''_t)}{v''_t \; v''} \right)}$$

EQUATION II

Values for the terms found in Equation II are obtained from the following sources:

v', v" -- from actual observations of moving traffic at the intersection.

y -- by the various factors such as pedestrian movement, width of street, etc.

s',s" -- from diagram of Figure 36, or Equation (12')
n',n" -- from actual observation of traffic flow for the different directions.
p',p" -- from observations at the intersection.
d',d" -- from measurements of the intersection.
v_t', v_t'' -- from diagram of Figure 35, showing the relation between traffic volume and left-turning speeds.
k -- from Table VI.

The curve for Figure 36 was plotted from the equation for time spacing:

$$(12) \qquad s = \frac{21 + 1.47\,v}{1.47\,v}$$

where s is the time spacing in seconds between vehicles, and v the speed in m.p.h.

The numerator (21 + 1.47 v), which is one of several expressions that have been advanced for determining the distance spacing between vehicles, was advanced by Dr. Bruce D. Greenshields, after an extensive field investigation, utilizing the photographic method to obtain the required data. It was chosen for this study because of its simplicity, and also because of having been based upon the analysis of a considerable amount of factual data obtained from actual field conditions as found in moving traffic.

Discussion of Formula for Cycle Length by C. P. Nachod

Case I -- Assuming No Left Turns

In the formula by C. P. Nachod, the symbols used are as follows:

s -- average time spacing for vehicles (as distributed) approaching the intersection(confined to single lane)
a -- average time spacing in seconds for vehicles leaving the intersection in groups -- assumed to be two seconds
t -- total cycle length in seconds
g -- green or GO interval in seconds.
A -- acceleration loss in seconds -- assumed to be four seconds.
D -- maximum number of vehicles per hour per lane on one street.

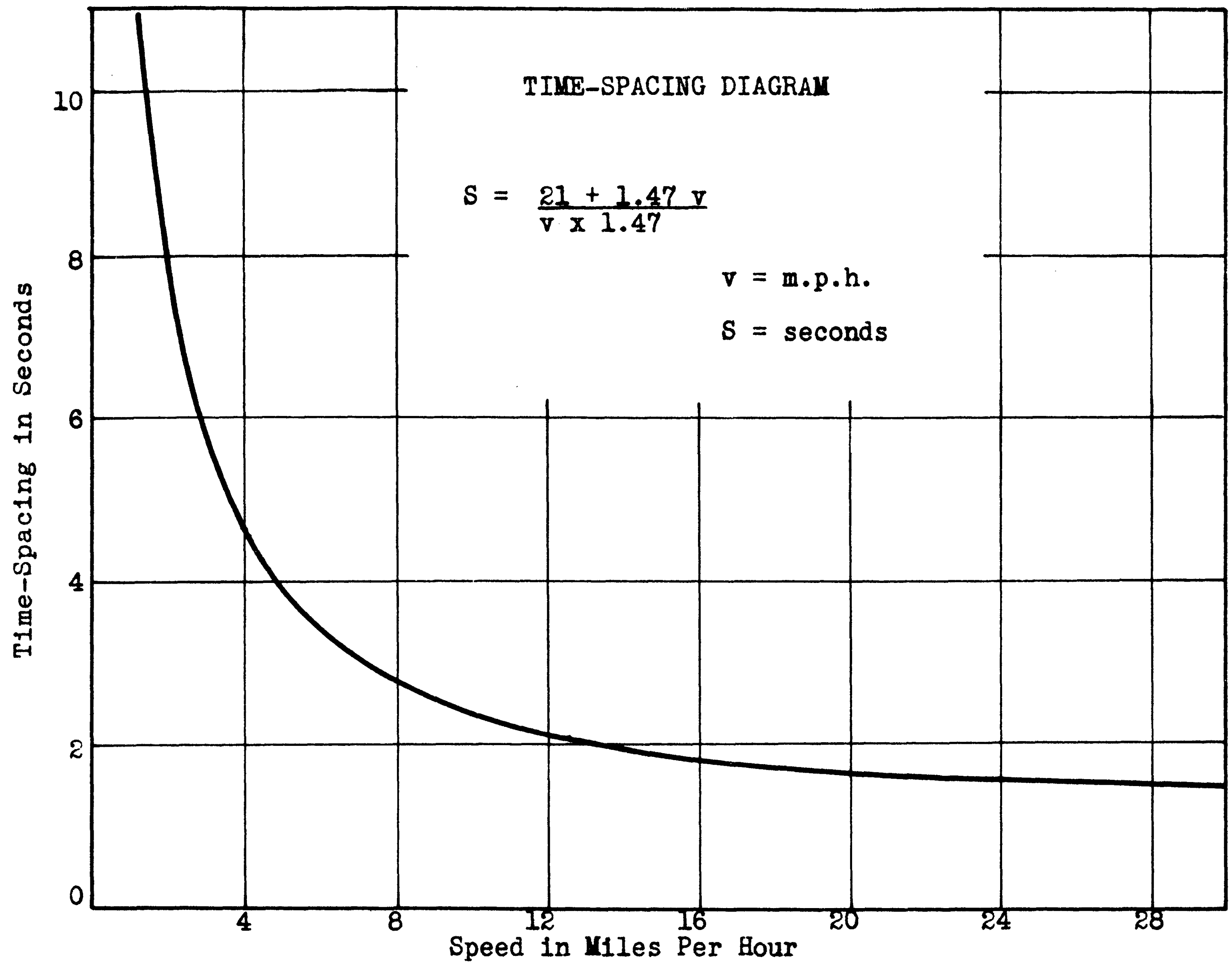

TIME-SPACING DIAGRAM
S = (21 + 1.47 v) / (v x 1.47)
v = m.p.h.
S = seconds
Time-Spacing in Seconds
0
2
4
6
8
10
4
8
12
16
20
24
28
Speed in Miles Per Hour

Fig. 36

n -- maximum number of vehicles per five-minute period

(13) $\frac{g - A}{a}$ = number of vehicles passing through the intersection on the green.

(14) $\frac{t}{s}$ = the maximum number of approaching vehicles that could pass the intersection.
But these two quantities must be equal; therefore,

$$\frac{g - A}{a} = \frac{t}{s}$$

Solving for g

(15) $g = \frac{at}{s} + A$

Then for the main and cross streets, respectively,

(16) $g' = \frac{at}{s'} + A$

(17) $g'' = \frac{at}{s'} + A$

(17') $t = g' + g'' = \frac{at}{s'} + \frac{at}{s''} + 2A$

$$at = \left(\frac{1}{s'} + \frac{1}{s''}\right) + 2A$$

Solving for t

(18) $t = \frac{2A}{1 - a\left(\frac{1}{s'} + \frac{1}{s''}\right)}$

The yellow interval was not included in Equations (16) and (17). If it had been considered, the numerator in Equation (18) would be

$$(2A + 2y)$$

Substituting a = 2 sec. and a = 4 sec.

(19) $t \quad \frac{8}{1 - 2\left(\frac{1}{s'} + \frac{1}{s''}\right)}$

(20) $D' = \frac{3600}{s'}$ $\qquad D'' = \frac{3600}{s''}$

$s' = \frac{3600}{D'}$ $\qquad s'' = \frac{3600}{D''}$

$n' = \frac{300}{s'}$ $\qquad n'' = \frac{300}{s''}$

$s' = \frac{300}{n'}$ $\qquad s'' = \frac{300}{n''}$

Substituting these values of s = f(n)
and s = f(D) in equation (19)

$$t = \frac{14400}{1800 - (D' + D'')} \qquad \text{EQUATION III}$$

Or

$$t = \frac{1200}{150 - (n' + n'')} \qquad \text{EQUATION IV}$$

Case II - Including Left Turns

Revising this formula by including the left-turning vehicles as a delay factor, and using the same expression for the delay in seconds caused by any number of left-turning vehicles as found in equation (9)

(21) $$g' = \frac{at}{s'} + A + 0.0033\ kp'n'td' \frac{(v' - v'_t)}{v'_t \cdot v'}$$

(22) $$g'' = \frac{at}{s''} + A + 0.0033\ kp''n''td'' \frac{(v'' - v''_t)}{v''_t \cdot v''}$$

(23) $$t = g' + g''$$
$$= a\left(\frac{1}{s'} + \frac{1}{s''}\right) + 2A + 0.0033\ t\ k\ p'n'd' \frac{(v'-v'_t)}{v'_t\ v'}$$
$$+ 0.0033\ t\ k\ p''n''d'' \frac{(v''-v'_t)}{v''_t\ v''}$$

Transposing and solving for t

(24)
$$t = \frac{2A}{1-a\left(\frac{1}{s'}+\frac{1}{s''}\right) - 0.0033\left(kp'n'd'\frac{(v-v'_t)}{v'_t\ v'} + kp''n''d''\frac{(v''-v''_t)}{v''_t\ v''}\right)}$$

Substituting n for s as in equations (20)

(25)
$$t = \frac{2A}{1-a\frac{(n'+n'')}{300} - 0.0033\left(kp'n'd'\frac{(v'-v'_t)}{v'_t\ v'} + kp''n''d''\frac{(v''-v''_t)}{v''_t\ v''}\right)}$$
$$= \frac{300 \times 2A}{300 - a(n'+n'') - \left(kp'n'd'\frac{(v'-v'_t)}{v'_t\ v'} + kp''n''d''\frac{(v''-v''_t)}{v''_t\ v}\right)}$$

Assuming $A = 4$ and $a = 2$

$$t = \frac{2400}{300 - (n'+n'') - \left(kp'n'd'\frac{(v'-v'_t)}{v'_t\ v'} + kp''n''d''\frac{(v''-v''_t)}{v''_t\ v''}\right)}$$

EQUATION V

Values for the different elements in Equation V are found as explained for Equation II.

NECESSITY OF CONSIDERING LEFT TURNS IN THE THEORY OF SIGNAL TIMING AT STREET INTERSECTIONS

Table IV shows the distribution of vehicles as to percentages using the inner and outer lanes, respectively. The total number of vehicles observed in this investigation was 5082. For the three intersections considered, where more than one lane was available in each direction, it is seen that practically fifty per cent of the vehicles used the inside lane. Taking these figures as a basis, it might reasonably be concluded that the inner lane should be considered as the critical lane, since the left-turning vehicles which, with very few exceptions, use this lane, exert a delaying influence on moving traffic, and require a greater amount of time to move the traffic through the intersection.

This study tends to prove further that the left-turning vehicles cannot be ignored when determining the length of cycle for any signalized intersection.

CONCLUSIONS OF INVESTIGATION OF LEFT-TURNING VEHICLES

If Chapter VIII, comprising the report on the investigation of left-turning vehicles had been limited to pages 114-151, which excludes the mathematical discussion of this data as applied to existing signal timing formulas, the following might have been properly set down as final conclusions.

1. The determination of the mean and median average speeds of left-turning vehicles and vehicles passing straight through, as found in Table III. An analysis of these speeds showed that they can be considered as a function of the volume of traffic passing through the intersection. This relationship is shown in the Curve of Figure 35.

2. The proportion of left-turning vehicles actually causing delay to other vehicles following in the center lane, as shown in Table V, and in Figure 34. From an analysis of this data it is further seen that a relationship appears to exist between the number of turning vehicles actually causing delay and the volume of traffic for the intersection. Table VI, sets forth this relationship in giving values for a reduction factor, k.

3. The proportion of vehicles using the inner lane when passing through the intersection was found to be ap-

proximately fifty per cent for the three locations observed, where more than one lane was available in all directions.

These results may therefore, be said to be two-fold, (a) the middle lane of traffic should be the critical lane where left turns are frequent enough, and (b) the left turns, which are made almost exclusively from this lane, cannot be ignored in traffic signal timing.

When considering the entire Chapter, including pp. 150-158, which is a mathematical discussion of traffic signal timing, the relative importance of the conclusions, (1), (2), and (3) as indicated above, take on quite a different aspect.

These "conclusions" do not lose any of their intrinsic value, but their relative significance may be said to be somewhat changed, taking the form of established facts, and serving as a means of arriving at two important conclusions. These are, the establishment of a "delay factor" due to left-turning vehicles, and by means of this "delay factor", the rationalizing of existing formulas for signal timing.

Viewing the report in this light the conclusions may be stated as follows:

1. Knowing the average speeds of turning and through traffic in an intersection, the former bearing a definite relation to the total volume of traffic, it becomes possible to establish a delay factor expressed as follows:

$$0.0033\ p\ k\ n\ d\ t\ \frac{(v - v_t)}{v_t\ v}$$

<u>k</u>--is a reduction factor which takes into account those left-turning vehicles which do not cause any delay to the vehicles following in the inner lane. Values for this factor are obtained from Table V, and Figure 34, and summarized in Table VI,

<u>p</u>--is the ratio of the number of left-turning vehicles to total traffic.

<u>n</u>--is the volume count for peak five minute periods.

<u>d</u>--is the distance from the outer edge of the crosswalk to the center of the intersection, and assumed to be the distance traveled by the left-turning vehicles during the time that they may be considered exerting a delaying influence.

<u>t</u>-- is the cycle length in seconds.

$\frac{v - v_t}{v_t\ v}$--is the time loss in seconds caused by one left turning vehicle.

This delay factor gives the amount of additonal time required to pass a number of vehicles n due to the turning vehicles actually causing delay.

2. By the introduction of this delay factor, existing formulas for signal timing were rationalized to include the left-turning vehicle, an element which under certain conditions exerts an appreciable influence on traffic flow at intersections

In the present formulas the cycle length t is the sum of the green periods required to pass the traffic through the intersection from the different directions

$$t = g' + g''$$

The green interval g is expressed as the sum of two terms as shown in Equations (4) and (5), for the Reeder Formula, and Equations (16) and (17), for the Nachod Formula.

The first of these terms consists of the time required to pass the volume of traffic through the intersection when movement is not affected by any obstruction; and the second term represents the time loss due to acceleration. (The Reeder Formula includes the yellow period, which may be disregarded for the present discussion).

By adding the delay factor as a third term to the expression for the green interval, and solving for t, the total cycle length, there results a rationalized equation which takes into account the time loss due to this disturbing element, the left-turning vehicle. See Equation II, and Equation V.

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