DRIVER AND TRAFFIC-STREAM BEHAVIOR

As Criteria for
The Design, Operation, and Control
of Streets and Highways

MICHIGAN

STATE HIGHWAY DEPARTMENT

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Planning and Traffic Division
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This preliminary copy of "Driver and Traffic-Stream Behavior" is submitted for your consideration.

Space has been provided on each page for your written comments, which are invited.

When you have completed your review, please sign this copy and return it to the Planning and Traffic Division.

Reviewed by ____________________

Date ____________________

FOREWORD

Troubles are cured by eliminating the causes; they are merely prolonged by treating the symptoms.

The troubles of motor-vehicle transportation are not exempted from this general rule; as a matter of fact, they are subject to it in a very particular degree. They will continue, and probably will increase, just as long as attention is directed to the treatment of superficial signs and effects. They will be cured only when the basic causes are found and removed.

The first step toward a cure is to reduce the problem to fundamental concepts by separating and simplifying apparent complexities. The second step is to find and enunciate acceptable principles which can be used to test the adequacy of existing roads, streets, and traffic control devices and to reveal the reasons for the faults that may be found.

It is the purpose of this paper to discuss basic factors of motor-vehicle transportation, to determine their part in causing highway troubles, and to outline the general principles by which the causes can be eliminated. It is hoped that it may help highway engineers to formulate better designs for highway facilities and to adopt improved methods for traffic operation.

The factual information used, and many of the principles cited, are derived from published reports of traffic investigations by recognized authorities in the field. The most important of these sources are listed for reference in the bibliography at the end of this paper.

PART I

COMMENTS

THE BASIC ELEMENTS OF MOTOR-VEHICLE TRANSPORTATION

Motor-vehicle traffic is one element of a vast and universal system of transportation which serves the needs of mankind. Before attempting to analyze the troubles of this one part of the total system, it is necessary to establish some basic concepts regarding transportation in general and regarding the place of the motor-vehicle in this system.

The fundamental truth is that civilization, and even life itself, depends upon the movement of people and goods from one place to another. This movement basically is individual and pedestrian, aided by such natural and mechanical means as the ingenuity of man has adapted or devised through the ages.

Currently the motor-vehicle is the most popular and most important of these mechanical aids. But the enormous movement of these vehicles does not alter the fact that it is the individual--going his own way for his own purposes--by whom and for whom all the devices for transportation have been created. Nor does it alter the fact that the individual traveling by this or other transport means, begins and ends every trip on foot.

These considerations point to the conclusion that roads and streets should be located, designed and operated to efficiently accommodate the transportation movement in the forms, the volumes, and the directions dictated by the desires of the people.

These are the basic elements of the motor-vehicle transportation system: The people; the paths by which they travel; the vehicles in which they move; and the

COMMENTS

rules and devices which control these movements

1. The People: Their Needs and Desires

The needs of people are basic. People must work; they must eat; they must clothe and educate themselves; they must have recreation and social intercourse. As long as the motor-vehicle continues to offer the satisfaction, convenience, and flexibility of personal ownership and individual control, people will continue to use it toward these needed and desired ends.

Motor-vehicle travel is largely necessity travel. The places which provide the essentials of living are the foci and the termini of the most vehicle-trips. The travel patterns created by these movements are basic, and they cannot arbitrarily be denied or radically altered on the grounds of economy, local expediency, or mere opinion.

The first principle then, of those we are seeking to establish, is that motor-vehicle transportation serves the needs and desires of people. Any portion of the transportation system is a functional failure to the extent that it denies these desires or serves them indirectly and inefficiently.

2. The Traffic Channels and Traffic Terminals

Roads and streets are the channels for traffic movement; parking and unloading spaces are the actual terminals of vehicular trips. The channels and the terminals are co-equal parts of the roadway system; a trip without a destination is hardly conceivable. Nevertheless, we are all prone to forget that an automobile is as useless without a place to stop as it is without a road to run on.

The location, design, and dimensions of both traffic channels and traffic terminals should conform to the needs and the characteristics of motor-vehicle travel, which are known or are ascertainable. These traffic facilities are produced by engineers, but they must be designed and built from the viewpoint of, and for the most efficient service to the people who use them. Only those engeneering and construction techniques and considerations which contribute to the provision of such service are applicable to the job.

A second principle then, is that roads, streets, and other traffic facilities are built for people and must be usable, understandable, and safe for people of practically all degrees of mechanical skill and mental perception.

3. Motor-vehicles and Their Operators

The basic or distinguishing characteristic of motor-vehicle traffic is that each component vehicle is subject to the will of an individual. The traffic-stream has motion and direction only; of itself it has no destination, and its composition and density are constantly changing as individual vehicles, seeking their individual destinations, enter or leave the stream.

It is important, at the very outset, to distinguish between the vehicle and the traffic-stream. Much confusion of thought will be avoided if each of these traffic components is considered as a separate entity, insofar as practical. This approach makes it possible to reduce the traffic problem to a few simple concepts, from which may be derived equally simple principles of design and operation.

In a very special sense the vehicle-and-driver aspect of traffic is concerned primarily with individual human beings, and with vehicles under individual human control. Deficiencies in rural highway geometric design and operation which

COMMENTS

are suspected of being productive of accidents, are readily evaluated in terms of vehicle-and-driver behavior. The fundamentals of the vehicle-and-driver relationship are: (1) the mechanics of driving; (2) the physiological limitations of the driver; (3) the physical characteristics of the vehicle.

The traffic-stream aspect deals with vehicles "in the mass"; - still individually controlled, but operating more or less in unison and amenable to collective regulation and control. The traffic-stream concept is particularly valuable in evaluating urban traffic problems. If vehicles could be made to operate in perfect unison and order, there would be no traffic congestion. Of course such perfection is unattainable, but it is possible to reduce congestion and increase street capacity by finding and removing the major causes of disorder in the traffic-stream. Order can be created by improvements in street usage, traffic operation, and traffic control. The tangible benefits of order in the traffic-stream are increased street capacity, lessened congestion, lessened delay, and increased safety.

4. Traffic Regulation and Traffic Control

The very fact that motor-vehicles are individually operated creates the need for controlling and regulating motor-vehicle traffic; the rights of the individual driver are, and must be secondary to the general welfare and safety. Regulation and control takes two general forms:

a. Rules for operating motor-vehicles, such as "rules of the road", which are nationally standardized and accepted.

b. Methods and devices for securing orderly movement and interchange of motor-vehicle traffic, such as traffic signals, one-way streets, parking regulations, and control of turning movements.

COMMENTS

In the second of these categories, there is always the possibility that in the interests of welfare and safety, certain devices or methods may hinder traffic movement and order more than is necessary. Restrictive devices in particular, must be carefully examined to determine if changes or substitutions could be made to avoid undue sacrifice of order and efficiency. There are many ways to reduce disorder and promote efficiency in the traffic stream, and it is only common sense to find and use the best.

Summary

Any element of design, operation or control can be evaluated by the application of these criteria:

1. Does it meet the needs and desires of people?
2. Is it compatible with the general welfare and safety?
3. Is it simple and understandable from the driver's viewpoint?
4. Does it conform to the known vehicle-and-driver limitations?
5. Does it promote order in the traffic-stream?

This paper is particularly concerned with the last three of these items, and the following chapters develop the concepts and principles involved. The first two criteria are very broad in scope and can be outlined here only in a very general way.

The Needs and Desires of People. The problems of highway and street location are essentially questions of the specific needs of particular areas. The needs and desires of people and the extent to which existing roads and streets serve them, are plainly revealed in the metropolitan area traffic studies and road use studies which the State Highway Department has conducted in recent years.

COMMENTS

The word "people" includes pedestrians as well as vehicle-drivers, and their needs and desires are fully as important in the motor-vehicle traffic problem as are those of the car driver.

The General Welfare and Safety. This consideration dictates practice and policy in design, operation, and control equally. The safety of pedestrians, particularly school-children, is of paramount importance. Other things to be considered are the essential and emergency services, particularly the operation of fire equipment and ambulances. Unwarranted property damage, the creation of flood hazards, disruption of school districts; these are a few of the things which must be avoided in the interests of the general welfare.

PART II

COMMENTS

THE DRIVER-VEHICLE UNIT

The individual driver in charge of his vehicle is the ultimate factor in problems of the accommodation of traffic. This is true whether he is operating practically at will on a lightly traveled rural road, is geared into the dense traffic stream of a major artery, or is seeking to find or to leave a storage space at a terminal of his journey. It is the satisfaction of his needs in these respects that comprises the principal obligation of the highway engineer.

The Driver's Viewpoint

The driver's "viewpoint", either physical or mental, has some bearing on every phase of the traffic problem. Of particular importance, however, is his physical viewpoint in relation to roadway design.

The driver's physical viewpoint is a perspective from a point a little over four feet above the roadway. This fact has tremendous implication as to what the layout, or geometric design, of all but the simplest level tangent roadway sections should be.

The records show that intersections, interchanges, and transitions in roadway cross-section are particularly fruitful sources of accidents and confusion. Both the accidents and the confusion are explained when it is considered that these roadway elements so often are designed and built with little consideration for the physiological limitations of the driver or the physics of vehicle operation. Only when they begin to operate in the presence of large numbers of drivers of widely varying skill and intelligence do their deficiencies become evident.

COMMENTS

The accident rates are indices of these deficiencies, and so are congestion and confusion; for many drivers are led astray by the design itself. Signs and warnings cannot wholly correct deficiencies of design, because there is no way to insure that all drivers will see and read the signs, or to insure that those who do read the signs will understand and heed them.

It should be remembered that roads are for the users and that they must be built to their standards of convenience and need rather than to those of the builders. These users represent all degrees of skill and intelligence from the highest to the lowest. Even if it is granted that the skill and intelligence of some of the users is equal or superior to that of the designer, there still remain the vast numbers of average and below-average users, whose skills will continue to be taxed by even the simplest situations, particularly when these occur unexpectedly or when they present illogical features. Again it should be considered that even those users of the highest skill and intelligence have little knowledge of the purposes and uses of such technical devices as channelization, ramps, speed-change lanes, and directional interchanges.

The principle of the "driver's viewpoint" is logically derived from these considerations, and can be stated in simple terms.

The driver does not see things in "plan view"; his picture, it must be reiterated, is from a point harldy more than four feet above the roadway. That is one of the reasons for the operational inadequacy of many intersections and interchanges that look "fool-proof" on paper.

Of course, these intersections appear simple and logical to the designer; they are simple and understandable from his viewpoint. He sees the layout in its

COMMENTS

entirety on a small-scale plan; an interchange covering forty acres can be detailed on a single plan sheet; every vehicle-path is plain and there is no apparent reason for confusion.

By contrast, - the driver, - the man who is to "operate" the design, - never sees it as a complete entity. On the contrary, he has a constantly changing and rather limited perspective view; he must make his choice of paths without any clear idea as to where they may lead. If he follows the most logical path, he often ends up far from his intended route; if he tries to read all the signs, he delays and irritates other users who are familiar with the layout through use. No matter how long the system has been in operation, no matter how many drivers have become familiar with it through daily use, there is always another stranger to create confusion and possibly to contribute to further accidents.

Ideally, the driver should be able to see in advance, enough of the layout for understanding, but not so much as to perplex him. He does not need to see the "why" of the design, but the "how" must be plainly apparent, simple and logical.

The Vehicle and Driver

The operation of a motor-vehicle usually is regarded as an exceedingly complex process. There is something wrong about this concept.

Complicated tasks in science and industry, and the operation of complex machinery, are reserved to technicians with exceptional skill and coordination, or with superior intellectual equipment; whereas virtually all of the adult population, including many of the physically or mentally handicapped, can and do operate automobiles on the highways.

COMMENTS

As to accidents, it is the manner and not the fact of operation which is the causative factor. Therefore it is in the manner of operation that the remedy should be sought. The mechanics of operating a motor-vehicle is a relatively simple skill which anyone of reasonably sound body and mind can acquire. The manner of operation also is basically simple; it is the repetition, always in the same order, of three functions or actions;

1. Perceiving
2. Deciding
3. Acting

For any given situation or condition, or combination of conditions, the driver must perform in rapid sequence, these three basic functions. He must observe, or "size up" the situation; he must decide upon a course of action; and he must react or carry out the determined action. Each function takes time, and as the combinations of conditions which confront the driver become more and more complex, the time required for these functions becomes greater. When the required perception-decision-reaction time becomes greater than the time available from point-of-sight to point-of-action, an accident can result. It is as simple as that.

A little thought will show that this basic formula is broad enough to cover all accidents. Accidents may be grouped into three general categories:

1. Mechanical failures
2. Physical and mental aberrations
3. So-called "errors of judgment"

Of course, there is no way that highway design can provide time allowances for critical unforeseeable emergencies, but the fact remains that they do conform to the basic concept of the perception-decision-reaction formula. Even in the case of a sudden mechanical failure or loss of consciousness by the driver, no accident will result if there is time enough, in the one case for the driver to regain control of his vehicle; and in the other case for the driver to regain consciousness.

COMMENTS

The manner of operation also is conditioned by elements not controllable by the driver, such as:

1. The amount, composition, and speed of traffic
2. The condition of the roadway surface
3. Visibility at different time periods and under varying weather conditions
4. Geometric design, including horizontal and vertical alignment

Under any of these conditions, the problem of accident-free operation is a problem in time-space relationships based on the perception-decision-reaction requirements of one or more drivers. Vision or perception, judgment or decision, and action or reaction are all functions of time.

Time: The Basic Dimension

The successful operation of a motor-vehicle depends on the time available for performing the basic functions of perception, decision, and reaction, and the mechanical operations of accelerating, decelerating and changing direction. Time is the essential requirement. All of the apparent complexities in the design and operation of streets and highways are simplified when reduced to this fundamental concept of time as the basic dimension. It may well be conceived as an absolute dimension, whereas distance and speed are relative dimensions only.

COMMENTS

The average perception-decision-reaction time for relatively simple situations has been determined as three seconds by laboratory and highway experimentation. For complex situations or for below-average operators, the time may be considerably greater. Most traffic conditions represent complex perception-decision-reaction situations and all traffic-streams have a considerable percentage of inept drivers. Therefore, any highway situation where the "time" available is near the minimum for the conditions, is most definitely an accident hazard.

Many examples could be cited to illustrate this fundamental rule: If geometric design, or traffic regulations, or physical conditions, create a situation with an inadequate time dimension, accidents will occur; they will occur in spite of signs, signals, and pavement markings; they will continue to occur unless and until the basic fault is corrected and the time dimension is increased.

The Physiology of Seeing

The first of the three basic functions of vehicle operation is "seeing". Seeing involves not only vision, but perception and also some degree of discrimination. The operator sees of course, inasmuch as he has eyes; but more than this, he must perceive intelligently and analytically, and at the same time discriminate between those objects and situations which concern him as a driver, and those which do not. Distracting scenes and objects are always present along the highway and the driver must consciously guard against having his perception and attention diverted to these irrelevancies.

In the physiological sense, "seeing" has a general - and "perceiving" a specific - meaning and application. Seeing is spread over the entire visual field, while perception is concentrated upon specific objects in the visual field.

COMMENTS

The most important facts in the physiology of vision as related to vehicle operation are:

1. Perception. The mind takes a certain amount of time to respond after the eye is stimulated by a single object. When there are two objects to be perceived or distinguished, the process takes nearly 50 percent longer; when there are five objects, it takes 100 percent longer. The more things the eye has to perceive, the slower the mind is in responding. This is the human physiology and this is its limitation. The mind of the vehicle driver needs time to respond to even a simple situation, and the length of time required increases rapidly as the situations become more complex.

2. Blind Spots. It is essential to know what the eye perceives when it is moving, and that is - nothing. The eye must "fixate" or look steadily at an object for a fraction of a second, before the object can be perceived. And when the eyes are moved from one object, or point of fixation, to another object, they perceive nothing clearly during the movement. This physiological truth explains many accidents, particularly of the intersectional type, and substantiates the truth of the familiar cry, "I never saw it coming!"

When a driver, approaching an intersection, glances to the right and then moves his gaze to the left, he may easily be blind to the fact that a car approaching from the opposite direction is making a left turn directly in his path. He may previously have seen this car approaching, but at the critical moment when it changes direction, he does not perceive it because he is not looking at it.

The eye needs about a sixteenth of a second to "fixate" or perceive an object. Therefore if the driver of a car approaching an intersection looks for traffic on

COMMENTS

each of the other three roadways, looks for pedestrians in his immediate and in his intended path, and at the same time must look for one or more regulatory signs, he may consume a half-second of time just in the process of seeing, before any decision, judgment or action can be initiated. This consideration further emphasizes the importance of the "time dimension".

3. Peripheral vision. The range of peripheral vision extends almost 90 degrees each way from the line of sight for the normal eye at rest. The "included angle" of peripheral vision is dangerously small in many drivers (gun-barrel vision), and in all drivers it decreases progressively with increased speed of motion. It averages 70 degrees at 45 miles per hour, 55 degrees at 50 miles per hour, and 40 degrees at 60 miles per hour. The eye is limited in what it can do, - and one of the things it cannot do is concentrate its vision to the front and spread it to the sides at the same time. And speed demands more intense concentration.

The peripheral range of the eye is called "vision" advisedly, rather than perception. The normal eye does not see at all clearly in the periphery; colors and shapes are distorted. Peripheral vision is more sensitive to motion than to bulk or shape; a motion in the extreme range of peripheral vision may attract the eyes, causing the head to turn and enable the eye to fixate and perceive the cause of the motion. During this movement of the head and eyes a "blind spot" and potential hazard exists.

It is a significant fact that peripheral vision is insensitive to color, and least sensitive of all to green and "box-car" red. Railroad trains, in their frequent colors of dirty reds, browns, and yellows against a green landscape, can be missed

COMMENTS

entirely in the driver's peripheral vision as they approach form the side, - sometimes with tragic results. It is hardly reasonable to suppose that a man will see a train and still drive into its path or its side, and yet this very thing occurs with tragic frequency.

4. Space perception. Judgment of the location, the speed, and the direction of movement of vehicles are problems in space perception.

Judgment of distance, or "range-finding" is largely dependent upon binocular vision; although it is a universal natural aptitude it varies greatly in individuals. Automobile drivers should be able to judge with consistent accuracy both absolute and relative distance. Many drivers do develop this aptitude to a high degree, but there is evidence that a large number of drivers are dangerously deficient either in space perception or in ordinary good judgment. The common practice of following too closely, the sudden application of brakes, and the over-shooting of turns, all indicate one or the other of these faults, or perhaps both.

Judgment of speed and direction of movement is dependent on angularity of vision, which is not a function of the eye or the individual, but derives from the relative positions of the eye and the moving object. When the object is moving directly toward or away from the eye the angularity of vision is zero; the only clue to motion, and a slim one it is, is the change in apparent size of the object. This rate of change is hardly discernible at a distance but increases rapidly as the object nears the eye; if the object is an approaching car, the range at which speed judgment becomes possible is dangerously short.

As a matter of experimental fact, motion in a car approaching in the direct line of vision is first discernible at about 800 feet, but rapidity of motion, or

COMMENTS

speed, becomes evident at less than 200 feet, - or a little over one second at ordinary highway speeds.

Objects moving at right-angles to the line of vision have the maximum angularity, and here the eye judges speed and direction of movement in relation to the background of fixed objects. It is therefore, relatively easy to estimate the speed of a vehicle approaching on a cross-road and take appropriate action; but when two vehicles approach each other in the same line of motion, - as in the center lane of a three-lane highway, - the judgment of speed and distance often is optically possible only when it is physically too late to do anything about it.

5. Night driving. Night driving lessens or handicaps all of the functions of the eye. Peripheral vision practically disappears, foreground vision is greatly diminished; focal distance is limited to the range of the headlights; space perception is uncertain, being dependent chiefly on the lights of approaching cars.

Much has been written on headlight glare as a factor in night driving. It is indeed a serious hazard, but it is very likely that improvements in headlight systems will reduce this hazard considerably; the remedy is after all only a technological problem.

Of much greater significance is the fact that the ability of the eye to do its job is greatly less at night. This is a physical limitation inherent in the structure of the human eye; it cannot be changed.

There are many conditions which aid the driver to make the most of his limited seeing ability at night. Familiarity with the route is a great help; so is sky luminosity and moonlight. Wide roads are easier to drive than narrow roads.

COMMENTS

There are also many things the road designer can do to aid the driver's eye in its night-time job. Chief among these are the use of contrast to outline the roadsay and the use of reflecting surfaces on signs, hazards, curbs and pavements. A driver rarely gets into trouble if he can see, and see in time.

6. Vision in rain, snow and fog. The greatest handicaps to vision are created by the various combinations of rain, snow, fog and darkness.

Rain cuts down visibility enormously, and especially at night. It reduces the contrast between pavement and shoulder almost to zero; it seriously and often completely reduces the visibility of roadside features, signs and other cars. At night, the wet pavement absorbs the light of the driver's own headlights and increases the glare of opposing headlights.

Fog can reduce visibility to zero, even in daylight. Either at night or in the daytime, the swirling pattern of fog in the headlight beams produces a confusing and hypontic effect on the driver, which serves to increase his difficulties.

Snow in the air produces this same hypnotic effect, in addition to reducing general visibility; and snow on the ground eliminates pavement edges, joints and pavement markings, leaving the driver completely disoriented. Under these difficult conditions, the vehicle driver needs all the aids which good design can provide. Chief of these are alignment and grades which will give him the maximum vision ahead, and reflective delineators to outline and orient the roadway.

7. Summary. These are a few of the reasons why it takes time to see. In every case road design can, and should, help the driver to make the most of his seeing ability. None of these handicaps can be eliminated, but all of them can be reduced.

COMMENTS

Again, the driver must have time to use his seeing ability. One cannot take a photograph of a stretch of road at one-hundredth of a second exposure, then study the plate at leisure and say, "This is what the eye sees in one-hundredth of a second". Actually the eye takes a measurable interval to fixate and perceive each element in the scene, and for the automobile driver this fixation and perception is a continuous process which must keep pace with the progress of the automobile, or confusion and accident are the result.

Safe speed is a function, - not of geometric design, - but of the time that is available for perception, decision, and action.

The Mechanics of Decision

Decision of course is a mental process, and the evaluation of mental processes is beyond the scope of this study. However, if decision is considered as being the time interval between perception and action, it becomes susceptible of measurement and analysis.

The process of decision, or evaluation, or judgment requires much more time, as a rule, than either perception or reaction. Seeing is, in a sense, a physical act and an involuntary one; one cannot help seeing and, although perception is not instantaneous, the time consumed is measured in small fractions of seconds. Physical reaction also is rapid, averaging perhaps a quarter of a second for the simple predetermined response.

The mental process which we have called "decision" involves analysis and judgement as well as final decision. Even the best mind requires a measurable period of time to analyze a situation and decide on a course of action. In the case of the

COMMENTS

automobile driver, however, we are concerned with the average or aggregate mind, and the estimate of average time required for decisions is probably a very liberal figure.

Experimental data throw a significant light upon this matter, but experimental data are based on controlled situations and predetermined responses. Even under these conditions, however, appreciable time intervals are required for the responses and the length of time increases very rapidly with the complexity of the situation. When a subject is required to choose one of five possible responses, his decision takes twice as long as when he is faced with a simple alternative choice.

Simple choice. Even in normal traffic situations, the automobile driver must first discriminate among the several facets of the situation, and then choose one of several possible responses or actions. The time required for this decision may be measurable in seconds, not fractions; and at sixty miles per hour an automobile travels 88 feet each second.

In a "simple choice" situation, the driver has one choice to make, and he can make it very quickly. A complicated situation can be simplified by breaking down the "multiple choice" into a series of "simple choices", separated in time. Thus, the situation stays within the power of the individual driver to decide "yes or no", and it gives him time to make each successive decision. The field of road design, and the field of accident records, are full of examples of "multiple choice" situations, where the driver does not have time to make up his mind.

Positive Decisions. It is, or should be easier to decide what to do than what not to do. The mind functions faster and better when confronted with positive, concrete facts; a vacillating mind may very readily produce an accident. Therefore all design and regulatory features should be simple and positive, and calculated

COMMENTS

to aid the driver in making a prompt decision.

"Stop" is a positive word; on a sign it means stop and nothing else; the driver's decision is easily made.

"Slow" gives the driver no clue to a decision; the word is relative and may mean different speeds to different drivers or to the same driver at different times or places.

A through road at an interchange should look like a through road, and a ramp should look like a ramp; the driver needs positive guidance, here of all places.

What does a driver do when confronted with three diverging roadways, all of the same width, surface type and gradient, set amid a forest of directional and regulatory signs? What is the driver's perception-decision-reaction time?

Action or Reaction Time

Reaction time is the interval between the decision to act and the initiation of the physical act itself. For instance, it is the elapsed time between the instant when it is realized that deceleration is necessary and the instant when the foot contacts the brake pedal. It is important only as a fraction of the total perception-decision-reaction time which is the vital roadway and traffic dimension. If the total dimension is adequate, it is immaterial what fraction is assigned by test or opinion to each individual function. If it is not adequate there is little point in arguing whether the driver failed to see, to judge, or to act, because it makes no difference in the result. The real question is, did he have time to do all three and then to complete the indicated action before reaching the point of conflict.

Summary

Here then are two basic tests which determine whether any specific road or part thereof is adequate for the safe operation of individual automobiles driven by persons of infinitely varying mental and physical capability.

COMMENTS

1. Does the driver have time to perceive, decide and act?

2. Are the number of things to see, to decide and to do, held to the practical minimum?

Significance of Driver to Roadway Design

The characteristics and limitations of drivers and of vehicle operation which have been described, all have direct implications regarding the design of roadways. The criteria for adequate roadway design in terms of individual vehicle operation are as follows:

1. Ample time for perception-decision-reaction.
2. Simple choice decisions.
3. Natural vehicle-path alignment.
4. Freedom from unexpected situations.
5. No forced decisions.
6. Roadway clear of obstacles.
7. Positive direction and regulation.

Three of the basic factors affecting vehicle operation need to be examined in greater detail. These are: The effect on the time factor of unexpected conditions; the significance of specific restrictions on the driver's lines of vision; and the action of physical forces for which allowance must be made.

Perception-Decision-Reaction Time and Design

The element of the unexpected often increases perception-decision-reaction time beyond computation or estimate. Unexpected situations develop due to traffic and

COMMENTS

weather conditions, and probably always will do so. But there is no reason or tenable excuse for the unexpected situations that are created by faulty design or operation.

The automobile driver is conditioned to "normal" driving where he can "anticipate" his decisions; in other words, there is a certain rhythm or standardization of operation. For instance, the driver on a rural highway is conditioned to driving on "his" side of a road of uniform width, with tangents and curves alternating. His line of motion, the road edge, and the road centerline are all parallel. When the road curves it curves as a unit and his line of motion follows it; when the road is straight, his line of motion also is straight.

Normally, therefore, the driver does not anticipate a road whose edges curve simultaneously in opposite directions while the centerline continues straight ahead into an obstacle; but that is what he encounters when a divider or median island is introduced.

All of his normal experience is upset and he is forced to a sudden decision and an unusual maneuver. He must steer a reverse-curve path where he had been conditioned to a straight-line path, and he is forced to this decision while his perception is still grasping at the fact of an obstacle in the middle of the roadway. This is what happens when the driver <u>sees</u> the obstacle and the warning signs; during a heavy fog or a driving snowstorm he <u>sees</u> little or nothing of obstacle and sign, so of course he <u>can do</u> little or nothing to avoid them.

Changes in width of a roadway, disorient the driver in much the same way and for similar reasons. In this case there is no obstacle in the road, but because of the forced change of path there is still a collision hazard. It is of the vehicle-vehicle rather than the fixed-object type.

COMMENTS

All of which leads to the enunciation of another basic principle. Design must provide a clear uniform roadway with flowing alignment and generous sight distances that afford ample time for necessary decisions. It is at fault if it presents such conditions as distorted alignment, unexpected changes, forced decisions, or obstacles in the roadway.

Driver-Vehicle Relationship

The driver's range of vision is limited by his position in the vehicle. The three fields of vision in which this limitation is most noticeable are; forward vision, side vision, and angular vision to the rear. The limitations and their significance in design are as follows:

1. Forward vision. The driver's eye-level is something less than four and one-half feet above the road surface in the newer models of passenger vehicles. His view of the road and its surroundings is a perspective from a low point of vision and is severely limited in rolling topography. Design has taken cognizance of this fact in the matter of providing sight distance over a crest, but has sometimes overlooked the equal importance of adequate sight distance at interchanges, intersections and changes in road cross-section. It is essential that all design features be analyzed from the driver's viewpoint, rather than from the plan layout; when this is done, many operational faults can be foreseen and corrected on paper instead of being immortalized in concrete.

2. Side vision. The location of the driving controls on the left side of the vehicle restricts the driver's vision to the right and downward; there is a "blind" area extending perhaps ten feet to the right of the vehicle. This restriction of vision has a definite effect on vehicle operation, particularly on curbed sections.

COMMENTS

On uncurbed sections the driver will operate his vehicle reasonably close to the edge of pavement, even though he cannot actually see it, because he knows that pavement and shoulder are more or less continuous and driving off the pavement will not be particularly hazardous. A curbed section, however, does present a definite hazard to operation and most drivers will insure a generous clearance from this obstacle which they cannot see. Therefore a curbed roadway must always be wider than an uncurbed roadway for equal operating safety and equal traffic capacity.

3. Angular vision to the rear. This is of importance particularly at the intersection of roadways. At a right-angled intersection the driver has little difficulty in looking left and right. When the intersection angle is less than 90 degrees, the driver must turn head and eyes, and even shoulders, so as to observe approaching traffic. When the angle is acute, even if the driver does twist around in his seat, his vision is blocked by the rear quarter-panel of his vehicle. Acute-angled intersections tempt the driver to skip the gymnastics and take the chance that no traffic is approaching. Consideration of these facts dictates intersection angles of not less than 60 degrees, and flow-in ramp design that will permit observation of traffic on the through highway from approximately a parallel path for at least the minimum perception-decision-reaction time.

Physics of Vehicle Motion

The motor-vehicle conforms to Newton's laws of motion the same as any other body of matter. These laws state that a body tends to continue in its state of rest or motion or direction of motion, until acted upon by some external force. The forces which act upon a motor-vehicle are generated by the actions of the driver; the external agency which applies these forces is the friction between

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tires and road-surface. Acceleration, deceleration and steering all are possible only be means of tire-friction, and when the needed friction is not available, the vehicle is out of control. It continues in its motion and direction of motion, or it remains at rest.

No computations or empiric rules of acceleration, deceleration or superelevation have validity unless they take into account the friction that is or may be available. Particularly significant is the friction available under the worst roadway and weather conditions that may occur. Hard and fast rules for stopping distance, superelevation, and safe or design speeds are open to dangerous misinterpretation unless the limiting conditions are clearly stated and recognized.

Changing the direction of motion of a vehicle likewise is subject to physical law. Since the steerable wheels of the vehicle cannot be turned instantaneously, it follows that the path of these wheels, and of the vehicle itself, is a spiral the dimensions of which are determined by the speed of the vehicle, the amount of time consumed in turning the wheels, and the frictive effect developed.

Design of curvature, superelevation, pavement crown, acceleration and deceleration lanes, and gradients should take into account these physical facts. A motor-vehicle cannot be operated successfully and safely under conditions which demand that it be maneuvered in conflict with unchangeable natural laws.

PART III

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OPERATION OF THE TRAFFIC-STREAM

The sum total of vehicles in motion on a road or roadway form a traffic-stream. The traffic-stream has certain characteristics of organization and movement which must be thoroughly understood as a basis for securing efficient street and traffic operation.

The "Traffic-Stream" Concept

Motor-vehicle traffic is the product of the concentration of individual vehicles upon a common path, and as such, has an infinite variety of gradations. However, within the range of possible concentrations of vehicles per unit of path, there are certain critical points which can be used to define three broad stages of traffic.

Traffic Density and Organization

The density of traffic is measured by the number of vehicles concentrated upon a unit length of path, be it street or highway. When there is little density or concentration, traffic consists of an irregular succession of individual vehicles, each moving entirely at the will and control of the individual operator. There is no "traffic-stream" in the accepted sense of the term. No traffic problems arise in the vehicle pathway, and where vehicle pathways conflict, the problems are in terms of individual vehicles rather than traffic-streams. The indices of this stage are low volume and low density and, usually but not necessarily, high speed.

At greater densities or concentrations, vehicles begin to form "trains" of

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varying lengths, with the vehicles in each train rather closely spaced. This is the true "traffic-stream", wherein the movement of the individual vehicle begins to be governed or conditioned by the other component vehicles, and the operator yields some of his freedom of action in the interest of the aggregate stream. Conflicts within the stream are negligible, while inter-stream conflicts require mass regulation rather than individual control. The indices of this stage are maximum volume or traffic capacity, optimum density or spacing, and relatively uniform speeds throughout the stream.

When densities exceed the optimum the vehicles form a continuous, close-spaced procession for long distances. Now the individual operator loses all freedom of action, conflicts within the traffic-stream are a serious and constant possibility, regulation of inter-stream movements is hindered by the sheer mass and momentum of the stream, and congestion is the result. This is a condition that occurs all too frequently on city streets and rural highways alike. The indices of this stage are lowered volume or capacity, extremely high density, and drastically reduced speeds.

When vehicle concentration is great enough to produce a traffic-stream, the inter-actions of individual vehicles are mutually modified and adjusted to produce a resultant mode of operation which is characteristic of the traffic-stream itself. Thus the traffic-stream acquires known characteristics and predictable actions; it becomes a transportation unit, and may be used as such in problems of design, operation, and control.

The Causes of Congestion

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When streets and highways are called upon to serve the movement of large volumes of traffic, sound economics demands that they function efficiently. Functional efficiency may be defined as the ability to handle large volumes of traffic at optimum speed, with safety and without confusion. Obviously many existing streets and highways fail to measure up to this standard.

Congestion is a manifestation of functional inefficiency. Lowered volumes and speeds do not produce congestion; neither does congestion produce low speed and volume. Rather, all three stem from the same cause, and congestion is the visible evidence that something is wrong.

Lack of order is the most conspicuous characteristic of congestion; it is an obvious inference that, since congestion and disorder exist together, there is a definite relation between them. It is also obvious that disorder is not only the companion, but actually the cause of congestion; and that the problem of eliminating congestion is the problem of identifying and eliminating the causes of disorder. Identifying the causes is a problem in analysis; eliminating them is a problem in design, operation and control.

The traffic-stream, the traffic channel, and the traffic-control devices are the elements of the motor-vehicle transportation picture. Therefore it follows that the causes of disorder are to be found in one or all of these elements. The problem in analysis is to find those characteristics of each which can, or do, give rise to lack of order.

If we can analyze these transportation elements and establish the basic re-

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quirements for the proper functioning of each, then a basic formula for creating and preserving order in traffic can be formulated.

Operations of the Traffic-Stream

The constant merging, separating, and crossing of traffic-streams and vehicles creates the traffic pattern. A little consideration will prove that all of the apparently complex maneuvers of traffic actually consist of some sequence or combination of these three basic movements.

A separating movement takes place every time a vehicle turns out of a traffic-stream of which it has been a part, or when a traffic-stream separates into two or more diverging streams.

A merging movement occurs when a vehicle enters into and becomes a part of a traffic-stream, or when two or more traffic-streams converge to form a single stream.

A crossing movement occurs when the paths of vehicles or traffic-streams intersect; it may be noted here that the crossing movement can be eliminated, while merging and separating movements cannot.

A turning movement is simply a separation from one traffic-stream and a merging with another; under two-way traffic operation, a left turn is a separation from the original stream, plus a crossing of an intervening stream, plus a merging with the objective stream.

Therefore, since all traffic maneuvers are reducible to three basic movements, it follows that disorder arising within the traffic-stream must have its cause in the time, place or manner in which these movements are made. But, since there is a right way and a wrong way of doing anything, there must be a right way of making

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these movements which are essential to traffic circulation. If the minimum requirements and optimum conditions for merging, separating and crossing can be established, we will possess a norm of traffic operation by which we can devise corrective measures for present ills and avoid the perpetuation of erroneous thinking in the planning of future traffic facilities.

Time-Gaps for Maneuver

The basic requirement, of course, is opportunity; that is, a place and a time for the movement. The place and time being adequate, the manner of making the movement should be orderly. The place and time are represented by a space, or gap, in the traffic-stream which will allow the desired movement, and disorder arises from the attempt to use, or the necessity of using, inadequate gaps.

"The concept of acceptable time-gaps is a very useful one. The flow and intermingling of traffic depend to a large extent upon the action of individual drivers. Each motorist has formed a judgement, based on his own driving experience, of the opening between two successive moving cars which is adequate for him to enter safely and comfortably, under given conditions of roadway and speed. It is presumable that this judgement is made on terms of time rather than distance, since the gap is actually moving along the highway, and the motorist's weaving or merging maneuver depends on his own speed, as well as that of the limiting cars. The determination of the time-gap acceptable to a large group of motorists under various traffic conditions should supply fundamental data for the design of highways to best accommodate the road users." 1/

1/ Technical Report No. 4, Bureau of Highway Traffic, 1948.

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As a matter of fact, considerable research and field observation have been carried on by the Bureau of Highway Traffic and the Highway Research Board to determine average minimum acceptable time-gaps for the various traffic maneuvers. The following table gives the average of values that are accepted by motorists under ordinary conditions.

Table 1

Movement	Acceptable Time-Gap
Weaving on one-directional roadways	1 1/2 secs.
Merging at non-stop locations (Ramps and traffic circles)	3 secs.
Merging at "Stop" locations	6 secs.
Crossing at "Stop" locations	6 secs.

Operating The Traffic-Stream

A traffic-stream has motion and direction, but no destination; it is nothing more than a train of vehicles which are bound in the same general direction for a period of time, but not necessarily to a common destination. If we visualize a single isolated stream of traffic, we can imagine perfect order prevailing so long as the speed and composition are constant. These remain constant only so long as there are no intersections nor other access points which permit merging, separating and crossing.

On the other hand, when intersections occur at frequent intervals and there is unlimited access between intersections, we have the disorder and congestion which is so characteristic of today's urban traffic. Obviously, we can reduce congestion and disorder by reducing the number of intersections and access points to the minimum consistent with the needs of traffic, and by designing them to induce orderly movements in the traffic-stream.

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This principle has been given practical expression in so-called "expressway" design, but the fact that the same principle holds true for all streets and highways, has been consistently overlooked. There are many degrees of application of the principle, just as there are many types of traffic facility, but it is a fact that the basic traffic movements can be made without disorder if acceptable conditions of time and space are provided.

Conditions for Acceptable Movement

Let us then determine, if possible, what may be considered as minimum acceptable conditions for the basic movements and the combinations of basic movements that occur under actual traffic conditions.

The simplest traffic movement is "separating"; that is, leaving the path of the traffic-stream. There is no time-gap requirement, because the vehicle simply swerves to one side and proceeds on its individual way; but there is a space requirement. If the movement is to be made without disorder, it must be made at about the speed prevailing in the traffic-stream, and therefore a space must be available outside of the traffic-stream for subsequent deceleration. Otherwise, the vehicle must decelerate while in the traffic-stream with the result that the trailing vehicles must likewise decelerate or swerve - either of which actions is forced - and more or less disorder ensuses.

In a traffic-stream flowing at optimum density, the sudden deceleration of one vehicle in this fashion can create locally a critical density and a loss of speed resulting in a wave of congestion and disorder that flows back along the traffic-stream

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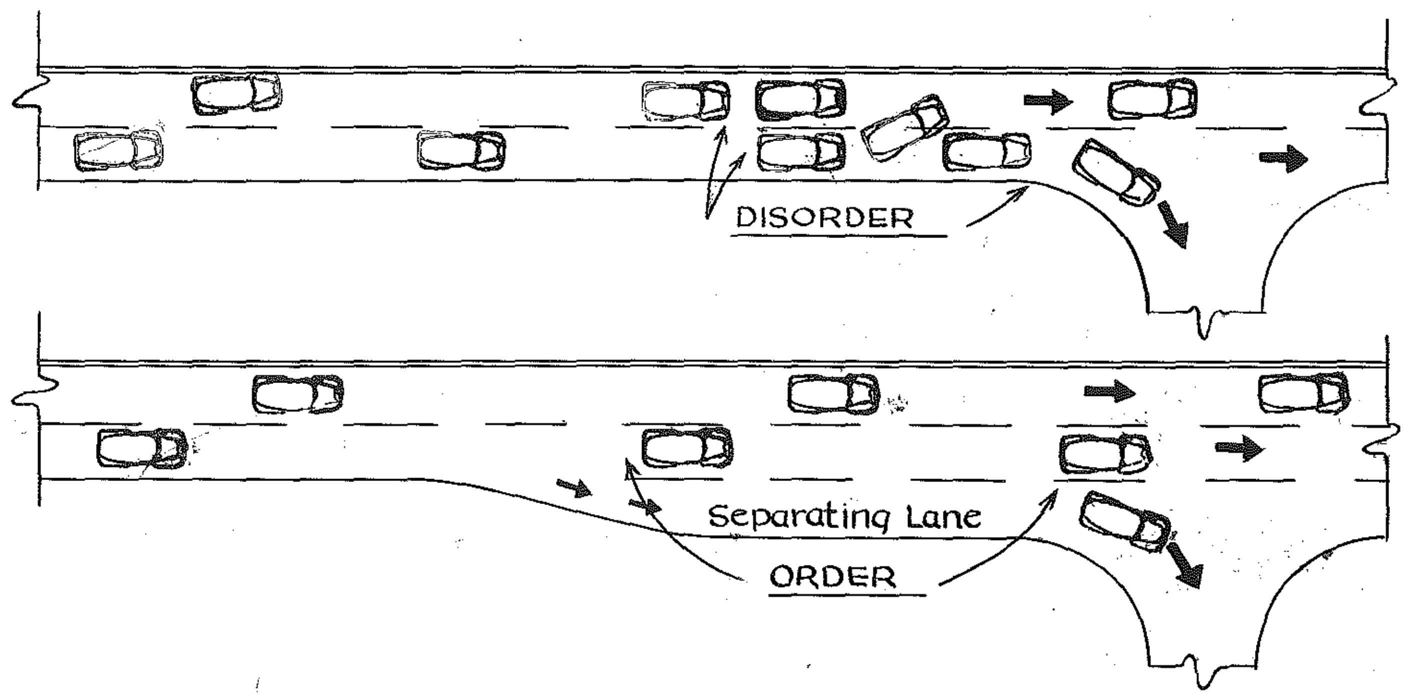
for a considerable distance. A series of such occurrences can bring about complete stagnation of the traffic-stream for long periods of time. These effects are particularly severe at high rates of traffic flow; where speeds also are high, the results are measured in both congestion and accidents.



The "merging" of vehicles into the traffic-stream is inherently more difficult since it requires the existence and utilization of a suitable gap in the traffic-stream into which the vehicles can enter, and it is more productive of disorder when improperly timed and executed. The matter of the occurrence of acceptable time-gaps is a function of traffic volume; within reasonable limits, the speed of traffic is immaterial, since the time required for merging is fixed by the requirements of the merging vehicle itself.

It has been determined by observation 1/ that the average driver will accept a

1/ Technical Report Nos. 1 and 4, Bureau of Highway Traffic three-second time-gap when he can match his speed with that of the traffic-stream (as when merging from an added lane); but he requires a time-gap of six seconds when merging from a standstill. Two facts are obvious: First, that merging can take place more often and more readily when a merging lane is provided; second, when the traffic density is so great that acceptable time-gaps do not occur, "forced" mergings may result with consequent disorder, unless artificial time gaps are created by some traffic control device.

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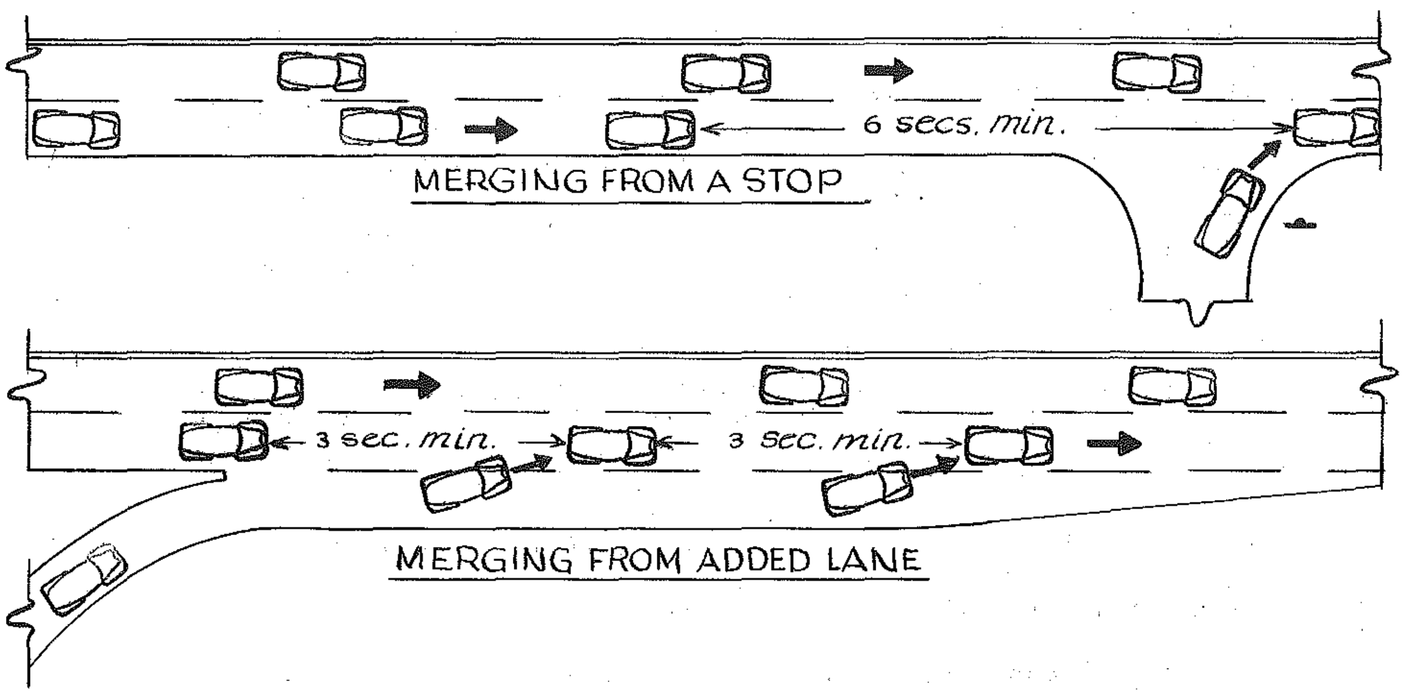
"Crossing" a traffic-stream presents essentially the same problem, but with



some differences arising from the fact that the vehicles or traffic-streams are converging on "collision courses" rather than flat-angle merging courses. An improper crossing movement, when it results in a collision, generally has more serious consequences than an improper merging movement. On the other hand, the

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crossing movement can be eliminated when traffic volumes so dictate, while the fundamental merging movement cannot.

The crossing movement, like the merging from a stop, requires a time-gap of six seconds. When traffic volumes are light, six-second gaps occur with considerable frequency, and crossings of the traffic-stream are easily made. With increased volumes, acceptable time-gaps occur less frequently, until a volume is reached at which no six-second gaps occur, and crossing becomes impossible.

The only recourse under these conditions is to create artificial time-gaps or eliminate the crossing. There are three ways of accomplishing these ends:

(a) The traffic-streams can be separated in time, by a traffic signal which allocates the crossing area alternately to each traffic-stream, or in other words, which creates artificial time-gaps;

(b) The traffic-streams can be separated in space, by means of a structure which carries one traffic-stream over the other, and thus eliminates the need for time-gaps by eliminating the crossing;

(c) The traffic-streams can be blended into a single stream, as by a traffic circle, thus substituting a merging-and-separating for a crossing, and making available the time-gaps in the three-to-six second range; this device also eliminates the "collision angle" and substitutes the flat merging angle.

Each of these devices has its merits and its faults, and each has a limiting range of conditions under which it will function efficiently.

A "turning movement" basically is the act of separating from one traffic-stream and merging with another, subject to the conditions previously discussed. It is of itself a simple maneuver, but it can become extremely complicated and disorder-creating due to the relations of traffic-streams; but it is this relationship of the traffic streams which creates the disorder, and not the turning movement. This fact will be demonstrated in a later paragraph.

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A weaving movement is the act of swinging from one line of vehicles into another line moving in the same direction; it is a separating and a merging performed at the prevailing speed of traffic. Weaving is a part of the passing maneuver, and also a part of the separating movement when it is employed to place the separating vehicle in the outside line. The time-gap requirements for weaving have been shown in Table 1.

Types of Street Operation

The relationships of the traffic-streams that constitute the traffic system dictate the time, place and manner of accomplishing these basic traffic movements. Motor-vehicle traffic functions at its worst when each roadway is occupied by two traffic-streams moving in opposite directions. It functions best under directional operation; that is, when each roadway is occupied by one traffic-stream. When these two systems are combined to include both one-way and two-way roads a compromise mode of operation results, the relative efficiency of which varies with the judgment used in the roadway arrangement.

Two-way Traffic Operation

The outmoded but still almost universal convention of two traffic-streams traveling in opposite directions within the same roadway is the direct cause of most of the disorder which harrasses our present transportation system. It is true that there are other conditions which give rise to disorder of a temporary, adventitious, or local nature. But two-way traffic, and the intense disorder created by two-way operation, are constant and almost universal.

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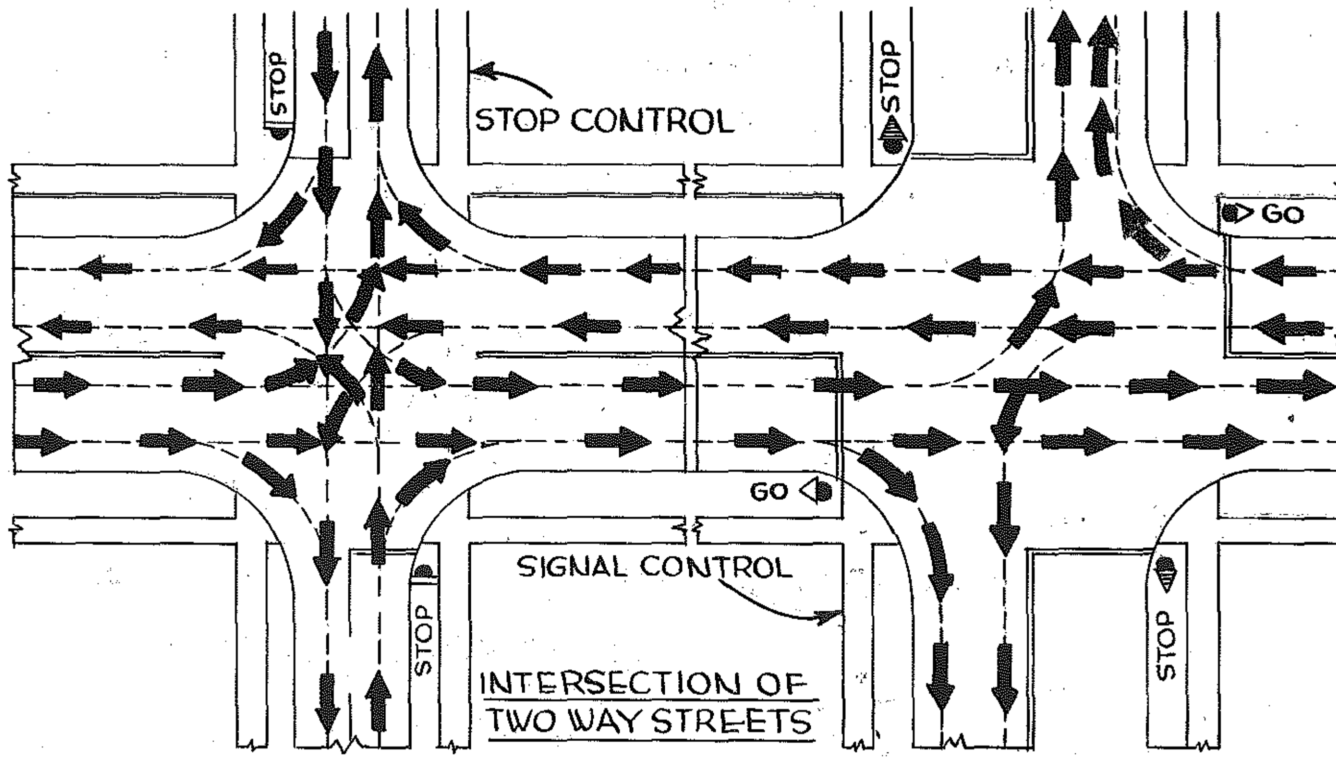

It is important that public agencies which are expanding time and money to improve traffic conditions, should realize this basic fault of the present system. At traffic-stream densities, the only reasons for two-way traffic operation are custom and construction economy. It is debatable whether "stretching" the construction dollar in this way is justified in the face of the demonstrable shrinkage of the "service" return from this type of traffic artery.

"Highway engineers have too long wrecked professional conviction against the stone wall of comparative per-mile costs. We need a new concept that recognizes the actual passenger-mile and ton-mile services returned, as the realistic measure of highway construction costs." 1/ It might be added, that the dollars-and-cents cost of accidents and congestion should also be recognized.

1/ Thos. H. MacDonald, Commissioner of Public Roads.

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The people who foot the bill for highway and street construction are the same people who suffer the economic losses arising from inadequacy of the facilities built with their own money.

Disadvantages of Two-way Operation

Two-way traffic operation lacks simplicity because of the preponderance of complicated movements, and it is time-wasting and irritating for the same reason. Accidents and congestion are inherent in two-way operation, and pedestrian traffic is severely handicapped. Let us see what happens to the basic traffic movements under this mode of operation which is so widely accepted, - not only as normal, but as actually desirable!

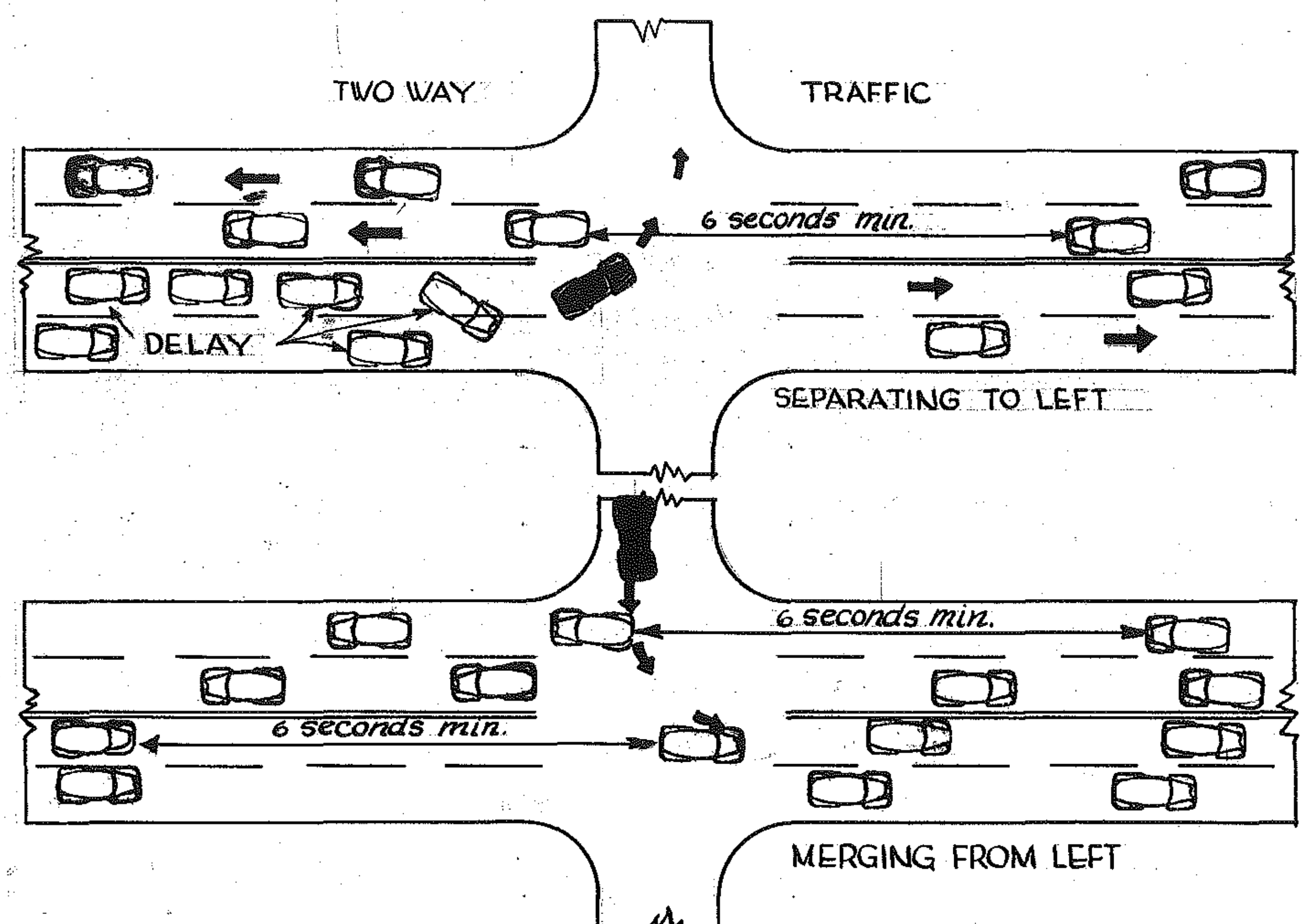
Separating to the right and merging from the right remain simple maneuvers under two-way operation. Separating to the left of the traffic-stream becomes a compound movement, involving separation from the parent stream and crossing the opposing stream. The ssing movement requires a suitable time-gap in the opposing stream and if such a time-gap is not immediately available the separating vehicle must come to a standstill and stand motionless in the traffic-stream for a time period which increases as traffic density increases. Thus the movement creates the greatest disorder during the very periods when order is most needed. When traffic densities are so high that acceptable time-gaps do not occur at all, the separating vehicle must force its way into the opposing stream, thus creating an artificial time-gap and at the same time compounding disorder.

Entering or merging from the left also is a compound movement which involves crossing an intervening traffic-stream before merging with the objective stream. A suitable time-gap is required in the first stream for crossing, in the second for

COMMENTS

merging, and furthermore these gaps must occur simultaneously. At high traffic densities such coincidences of time-gaps are infrequent. Furthermore, the situation imposes upon the driver a condition of multiple perception and decision which violates one of the principles enunciated in the previous chapter.

Crossing movements involve this same coordination of time-gaps, when they occur at stop-controlled intersections. Furthermore, they impose on the driver an additional perception requirement; not only must he perceive and judge traffic to the left and right, but also he must watch for a possible left turn from the opposing traffic-stream.



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Under two-way operation, vehicles can enter or leave the traffic-stream only when suitable opportunities, or "time-gaps", occur. In a general way, these required conditions may be summarized as follows:

Table 2

Movement	Time Conditions
1. Leave to the right	None
2. Enter from the right	A time-gap of 3 seconds or more in the adjacent traffic-stream.
3. Leave to the left	A time-gap of 6 seconds or more in the opposing traffic stream.
4. Enter from the left	Simultaneous time-gap of 6 seconds or more in both traffic-streams.

The first of these movements only can be made at the will of the driver and without creating disorder in the traffic-stream. The other three movements are restricted by conditions, and create more or less disorder accordingly as the driver must wait a longer or shorter time for the required time-gaps to develop. The following table indicates the relative chances of making any one of these movements under free-flowing traffic conditions at different rates of traffic-flow. 1/

Table 3

Rate of Flow in Each Direction	Percent of the time that conditions will permit:		
Veh. per Hr.	Entering from Right	Leaving to Left	Entering from Left
400	72	51	26
600	60	37	13
800	51	26	7
1000	43	18	4

1/ See Appendix

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Under two-way operation, traffic functions in an orderly manner only when the merging and separating movements are confined to the clockwise direction. Counter-clockwise movements are not compatible with two-way operation. Inasmuch as traffic desire is a legitimate reason for these movements, while no valid argument exists for two-way operation, it would seem that the way to more orderly traffic operation lies on the almost virgin pathway of directionalism rather than the well-beaten road of indiscriminate "No Turn" signs. The important fact to consider is that the latter device is applicable only at intersections, while directionalism brings order out of disorder and confusion in both mid-block and intersection locations.

Where there is conflict there is disorder, and conflict is inherent everywhere in the two-way operation of traffic.

One-Way Traffic Operation

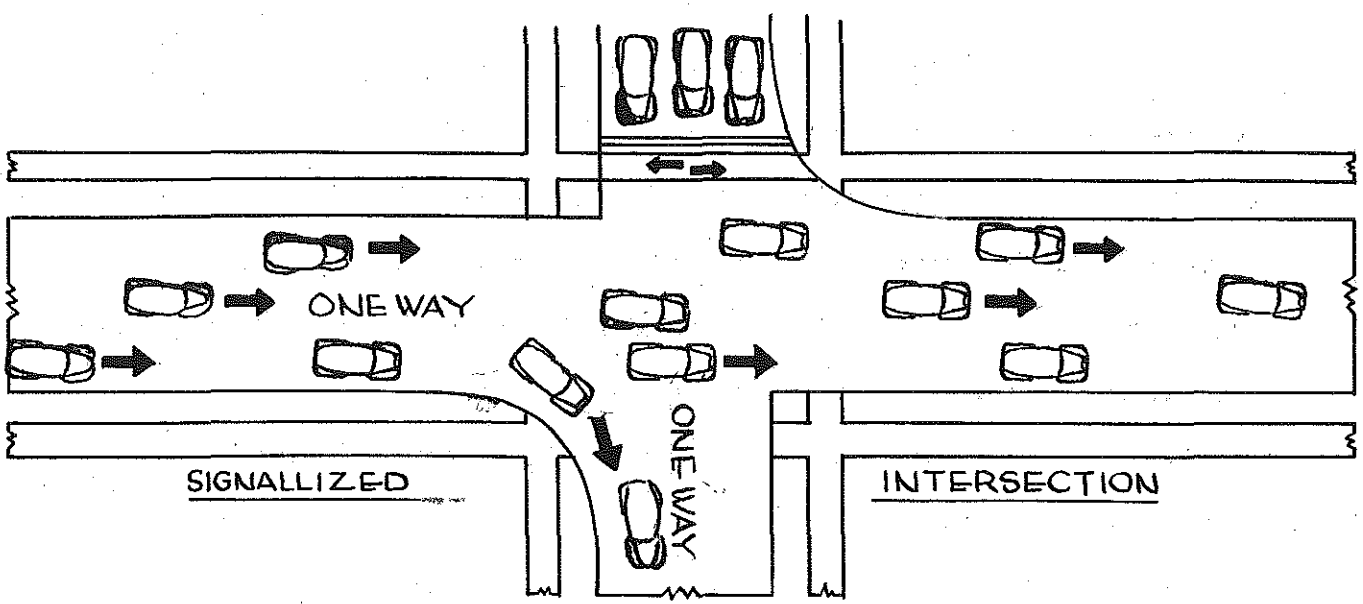
One-way, or "directional" traffic operation permits maximum order and efficiency in the inter-relations of traffic-streams and the independent movements of the individual vehicles. All of the basic traffic movements can be made with equal freedom to left or right, and all the desires of traffic can be accomplished by these basic movements alone; there are no "compound" movements under directional operation. Thus one-way traffic operation conforms fully to the precept of providing for the needs and desires of traffic in the most direct manner.

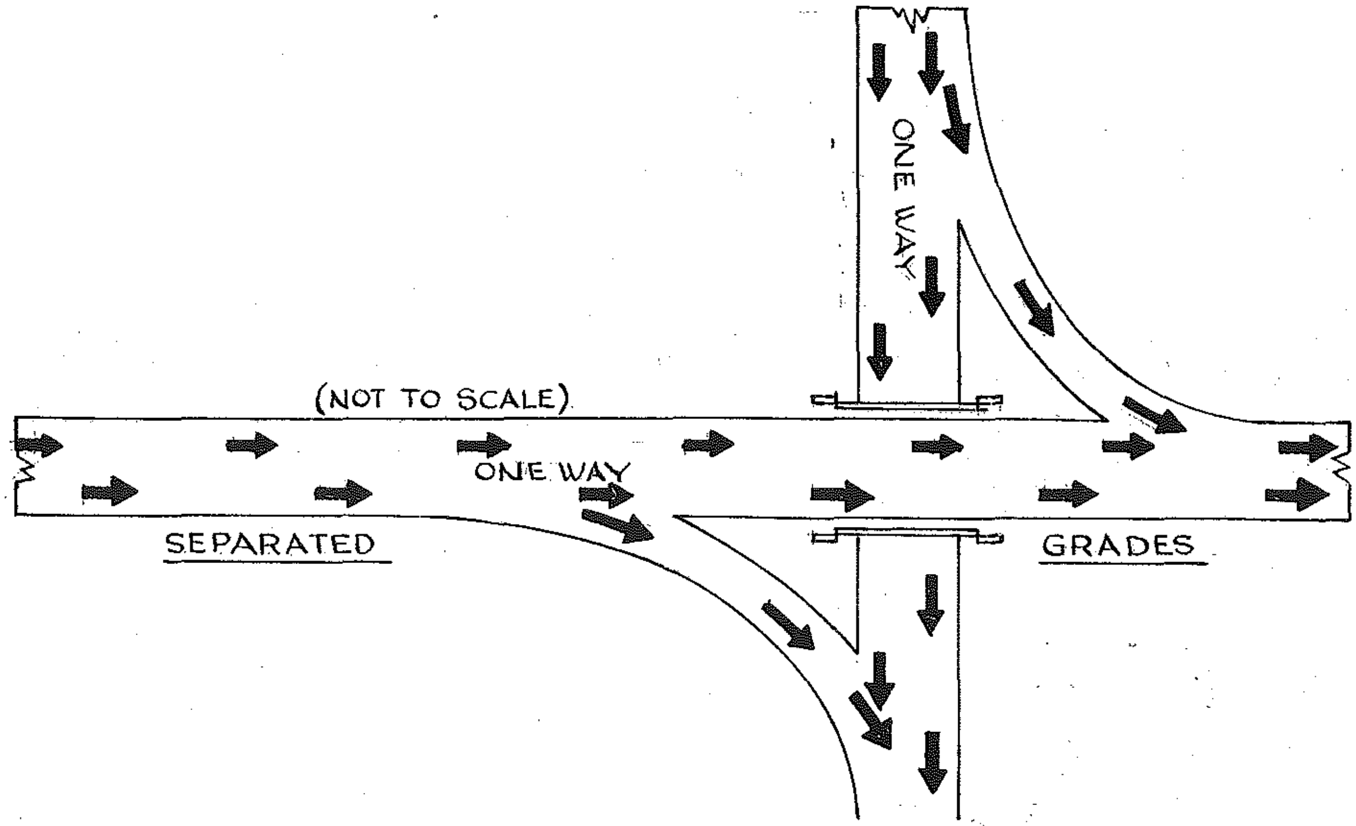
Simplicity, safety, and minimum time-gap requirements are the key features of directional traffic-stream operation. Simplicity because all movements are made with equal freedom to left or right and without conflict with opposing traffic-streams. Safety because the need for attentiveness exists in only one direction

COMMENTS

instead of both; with less attention demanded by vehicular traffic, the driver has more time to observe pedestrians, signs, and signals. Minimum time-gaps because, with less complex judgments to form, the driver can consistently accept smaller time-gaps for his desired movements, particularly crossing movements at stop-controlled intersections.

The crossing of two one-way traffic-streams is the simplest form of intersection; it operates ideally under any type of control, requires minimum construction, and offers the best pedestrian conditions. It is the simplest, because the number of possible movements is minimum; ideal in operation, for the same reason; and economical in construction because the roadway can be built to fit the traffic. In addition, the pedestrian gets a much-needed break because he is exposed to "sniping" from only one direction, and because - at signalized intersections - there is always one cross-walk entirely free of vehicular traffic.





Compromises in Traffic Operation

The compromise traffic system may take either of two forms: (1) Some arteries in a specific area may be directional and the remainder two-way; or (2) Some or all of the arteries may be so-called "dual" roadways.

The first of these expedients will be only as effective as the logic exercised in selecting and regulating the system. If the directional streets are established without regard to the desires of traffic, their effectiveness will be impaired; it can be killed entirely by arbitrary restrictions unrelated to the overall plan, - such as the haphazard prohibition of turns for momentary expediency.

The effectiveness of the dual roadway, either alone or as a part of a dual-

COMMENTS

roadway system, increases with the width of the separation between the traffic-streams. This separation may vary from a very narrow divider, which in effect provides more positive delineation than a paint line, to a very wide "median strip" which in effect creates two one-way streets. If the divider is not at least wide enough for vehicle-refuge, it will not in any way facilitate the counter-clockwise traffic movements either at or between intersections.

Therefore the narrow divider does nothing toward reducing conflicts in and between the traffic-streams, although by its delineating effect, it may promote better organization, and hence more orderly movement, of traffic as a whole.

SUMMARY

Merging and separating are the basic traffic-stream movements. Crossing and weaving movements arise when individual traffic-streams interweave to produce an actual traffic system. These are the four movements by which traffic functions.

The basic requirements of traffic operation are, of course, channels for the movement of vehicles and terminal areas for the storing of vehicles. If we are to have free and orderly traffic operation however, we must add two more basic requirements: - time and space for the execution of the basic movements without disruption of the traffic-stream. These time and space requirements are ascertainable, within reasonable limits, for each movement.

Directional operation meets the desires of traffic in the simplest manner. Access to, and egress from, the traffic-stream is equally free to the left or right. The intersection is reduced to its simplest form, and traffic-stream conflicts are eliminated. Of equal importance is the fact, previously mentioned, that at the inter-

COMMENTS

section of two one-way streets there is always one cross-walk free for pedestrian traffic. Separation of grades on one-way roadways is accomplished with an extremely simple ramp layout.

Under two-way operation, access and egress in the counter-clockwise direction become compound, rather than simple, movements and their excessive time and space requirements can be met only at the expense of disorder in the traffic-stream. The intersection of two two-way streets creates six traffic movements and four traffic conflicts, and at no time is there a cross-walk free for pedestrian use. The separation of grades on two-way roadways involves complicated, circuitous and expensive ramp connections.

The dual roadway functions to the extent that it approaches a pair of one-way roadways. The central divider must be wide enough to accommodate crossing and counter-clockwise movements with a reasonable degree of order, or it is of little utility in reducing conflict and congestion.

PART IV

COMMENTS

USAGE AND DESIGN OF TRAFFIC CHANNELS

The traffic channel itself may contribute to lack of order in three ways. Disorder may arise from the usages imposed upon the traffic channel, from the dimensions and geometrics of the traffic channel itself, or from the discontinuity or poor arrangement of a system of traffic channels.

Usage

Streets and highways are traffic channels; their function is to provide for the free movement of vehicles and pedestrians from origin to destination. If they are to perform this function with any degree of efficiency, their usage must be limited to these essential movements. Non-functional usages create disorder by dislocating the traffic-stream and reducing the usable width of street; the result is decreased capacity, speed and efficiency.

Types of Usage

The so-called "expressways" in urban areas, and to some degree the rural highways in general, are "limited usage" and, to the extent that they are so limited, they exhibit the presence of order and the absence of congestion.

At the other extreme is the urban arterial street as it exists today. Here the functional usage is hindered and all but denied by the numerous non-functional usages and the disorder they create. Curb parking, double parking and cruising are completely non-functional usages. Loading and unloading of commercial vehicles is a non-functional usage, while the presence of heavy commercial units is a usage which, though of itself functional, can and should be restricted to specific truck

COMMENTS

routes. Bus loading and bus operation also are functional usages specifically rather than generally.

Curb Parking

The gross effect of curb parking on street capacity is tremendous. First, it actually reduces the usable width of street by about seven feet each side; this is the physical space occupied by a line of parked cars. Secondly, it creates disorder in the traffic-stream and a consequent loss in capacity equivalent to a reduction in street width of another seven feet each side. Field observation has proved that a forty-foot street without parking has the same traffic capacity as a sixty-eight-foot street with parking on both sides.

Added to this is the disorder created by double parking and cruising, which are the side-effects of curb parking. The disruption of traffic-flow caused by these practices is not readily measured quantitatively, but observation will show that it is very considerable; the proportion of cruising vehicles in the traffic-stream has been estimated as high as thirty percent on downtown streets during certain hours, and the analysis of metropolitan area traffic study data has indicated that this is an acceptable estimate.

Other Terminal Uses

Loading and unloading of commercial vehicles is a necessary function of commercial and industrial establishments, but it is a non-functional street usage which creates extreme disorder if permitted during high-traffic periods. The back-door is the traditional channel for delivery of merchandise throughout the residential areas of the city; the conformance of the downtown merchant to this tradition is necessary in the interests of order. It is attainable through good planning.

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Mass transportation is an integral part of traffic, particularly in urban areas, and mass transportation requires loading zones, usually but not necessarily within the street. Street loading zones create disorder in the traffic-stream. Where it is not feasible to use off-street loading facilities, it is essential to space and locate the loading-zones for minimum disruption of the traffic-stream.

Reasonable Adjustments

The elimination of non-functional uses of streets and highways can and will produce order, increased capacity, and lessened congestion; the amount of the improvement will be in direct ratio to the reduction of disorder. Street usage is the major source of congestion in the central business district. It is a principal source in other non-residential areas such as shopping centers, industrial areas, and on arterial streets. It should be obvious that congestion and disorder will continue just so long as streets are required to accommodate the mutually antagonistic functions of vehicle movement, vehicle storage, and pedestrian activity.

Since the function of streets is to provide land-use access, it follows that neither moving vehicles nor pedestrians can well be denied the use of the streets; but the elimination of vehicle storage and its attendant abuses is practical. Such a step would reduce disorder by reducing conflicts, by reducing cruising traffic, and by providing more street surface for the use of moving traffic. This reform in street usage can be accomplished over a period of time, by regulation and ordinance; but only if and when alternative off-street storage

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has been provided.

Dimensions and Geometrics

Lack of order is created by both dimensional and geometric faults. It is obvious that a street or highway can be so narrow as to constrict the traffic-stream and produce disorder; it is also true, though not so obvious, that a street can be so wide as to induce disorder by the very fact that the traffic-stream has too much freedom. This is indicated by the fact that street capacity per unit of width decreases as streets become very wide; the work of the Highway Research Board on capacity shows the optimum street widths under various conditions of operation as follows: 1/

Table 4

Area	Type of Operation	Kind of Parking	Optimum Width	Cap. per 2/ 10' per gr. hr.	Relative Efficiency
Downtown	One Way	No Parking	46-50'	838	100
"	Two Way	"	50-54'	745	89
Intermediate	One Way	"	32-36'	740	88
"	Two Way	"	42-46'	670	80
Outlying	"	Immaterial	44-48'	648	77
Intermediate	One Way	One Side	42-46'	612	73
Downtown	"	"	48-52'	580	69
Intermediate	"	Both Sides	58-62'	505	60
"	Two Way	"	62-66'	480	57
Downtown	One Way	"	52-56'	422	50
"	Two Way	"	56-60'	420	50

1/ See Chart in Appendix
2/ Per green hour, or when traffic control signals permit traffic to flow.

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This table also confirms the fact that no street can be an efficient traffic channel so long as it is used for vehicle storage.

Another dimensional requirement is adequate radii for turning traffic at intersections. When an intersection is so constricted that vehicles must use part of an adjacent lane for turning, disorder in the traffic-stream results. Intersection radii should be sufficient to accommodate, within the limits of the turning lane, the largest vehicles that may habitually use the intersection.

Street Widths

A two-lane, two-directional highway or street becomes dimensionally inadequate when the traffic density is sufficient to produce a traffic-stream. Below this density the roadway carries a succession of individual vehicles in each direction and these vehicles can interweave in an orderly fashion, as the occasion occurs, and at the will and the control of the individual driver.

A city street is too narrow when it creates crowding and disorder in the traffic-stream; it is too wide when it encourages lane-straddling and "open field" operation, or handicaps pedestrian movement.

The minimum design for two-way streets and highways where traffic-stream densities frequently occur, is two "moving" lanes in each direction. This allows the orderly operation of slow-moving and faster-moving traffic. There is some evidence (see table 4) that this also is the most efficient width; wider streets not only are less efficient per unit of width, but they also impose severe hazards to pedestrian movement.

In areas of heavy pedestrian traffic, the pedestrian is entitled to a refuge area when he must cross more than two lanes of moving traffic. Where vehicular

COMMENTS

volumes demand street widths of this order, one-way streets in pairs are more efficient per unit of width than extremely wide two-way streets, (see table), and are more favorable to pedestrian traffic in that the pedestrian needs to watch only in one direction when crossing.

Dimensional and geometric inadequacy contributes to lack of order both in the rural highway system and in the urban street system.

Other Factors

One of the principal faults of geometric design, as measured by the disorder it creates, is the failure to provide for the known needs of the traffic-stream at specific locations. Where a heavy turning movement exists, deceleration storage lanes should be provided so that the turning vehicles may separate from the through traffic-stream with the minimum disturbance. Proper channelization will produce orderly movements at points of traffic interchange, instead of disorderly movements. Proper placement of curbs and roadside structures, the elimination of confusing joint-layouts, and uniformity of width and surface-texture will induce orderly lane usage by the traffic-stream.

Sudden sharp curves and jogs produce disorder by causing a sudden decrease of speed accompanied by a sudden increase in density. This often produces a considerable drop in volume and a wave of congestion which travels back along the traffic-stream for a considerable distance from the point where the congestion originates. Many drivers also find it difficult to stay within lane limits when negotiating curves and jogs in heavy traffic; this is a further cause of disorder at such locations.

Continuity and Arrangement of Street System

The "layout" of a street or highway system aids or hinders order in the traffic-stream. This is particularly true of city streets, but it also applies in a lesser degree to rural highway systems. Arterial highways and arterial streets should be continuous and of reasonably direct alignment throughout their length. The arterial street system of almost any city today is cursed with discontinuous streets, and the resultant constant "jogging" of the traffic-stream from street to street is a major cause of disorder. As a typical example, Lansing had two continuous east-west arteries (Saginaw Street and Mt. Hope Avenue) and no continuous north-south arteries until recently, when Larch Street and Cedar Street were hooked up by new construction. Lansing even yet has no continuous arterial street passing through the city near the central business district. Discontinuous streets breed turning movements, and excessive turning movements are the greatest cause of disorder in the traffic-stream itself.

Faults in the pattern, design, and usage of the street system which are breeders of disorder, and which are all too common, are:

1. Narrow inadequate bridges which create bottlenecks and disorder.
2. Insufficient bridges. (Many streets which now end in tee-intersections could be made into useful continuous arterials simply by building bridges)
3. Railroad grade-crossings; particularly those were peak-hour street traffic and railroad shunting or train movements coincide.
4. Abrupt changes in street width.

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Summary

The traffic channel will contribute to lack of order, congestion and inneffi-ciency as long as these conditions obtain:

1. Usurpation of the traffic channel by non-functional usages.
2. Dimensionally inadequate streets.
3. Geometric design that hinders the freedom of the traffic-stream.
4. Failure to provide for pedestrian needs.
5. Discontinuity of arterial streets.
6. Periodic interruptions of traffic flow.

PART V

COMMENTS

THE TRAFFIC CONTROL DEVICES

We have seen that disorder can arise from the movements of the traffic-stream itself, and from the usage and arrangement of the traffic channels. Still another fertile source of disorder exists in the misapplication of traffic control devices; that is, the signs and signals which are installed to control and regulate the actions of vehicular and pedestrian traffic.

Effect and Proper Use of Traffic Controls

The impact upon traffic of the control devices is two-fold. First, the simple fact of the existence of control devices demands perception and attention from the driver and in so doing they divert some part of his attention from the business of driving. But since signs and signals are a basic and integral part of the transportation system, this condition must be accepted. Secondly, the number, location, timing or purpose of signs and signals can usurp too much of the driver's attention, impose upon him multiple decision situations and, when improperly chosen, may create delay and irritation in the traffic-stream and hinder the orderly flow of traffic. These evils can be kept to a minimum by observing these fundamentals:

1. Use signs and signals only where they actually are necessary to preserve order and safety in traffic. Unnecessary and arbitrarily restrictive signs tend to create an attitude of indifference or resentment toward all signs. (It would be interesting to know how many drivers do pay attention to signs, and to which signs they pay the most attention.)
2. Place all control devices as nearly as possible within the normal range of vision of the driver and the pedestrian. Neither the driver nor the pedestrian

COMMENTS

should ever have to hunt for a sign which may mean to him the difference between safety and disaster.

3. Signals in particular, should show clearly against a contrasting and uncluttered background. The warning face or lens of the signal may well be extra large or distinctive in outline, since it is the vital element.

4. Signs must be legible at sufficient range to allow time for the action prescribed; they should be positive in text and should not contain the slightest ambiguity. Above all, they should be readable at a glance and understandable by anyone with the wit to obtain a driver's license; the best sign contains the fewest and the simplets words.

5. The control devices in any closely-knit system of roadways, - such as the downtown areas, - or on a continuous arterial thoroughfare, should be integrated and coordinated to produce a definite, calculated pattern of operation. The haphazard placement of control devices for temporary expediency, - such as "No Left Turn" signs, - inevitably provokes driver irritation and often results in increased, rather than lessened, disorder.

6. Many existing signs are little more than tacit confessions of error in design. It will always be more effective, and sometimes cheaper in the long run, to correct an error rather than erect a monument to commemorate it. Warning the traveling public as to why a road is dangerous, instead of removing the source of danger, is morally indefensible; the more so as there is no way of insuring that the public will perceive the warning.

Specific Traffic Control Devices

A few words of discussion on the more common traffic control devices may be in order. The three main devices for regulating the flow of traffic are; the "stop" sign, the traffic control signal, and the "no turn" sign.

COMMENTS

The "Stop" Sign. The most elementary, and probably the most common, traffic control device is the stop sign. The necessity for a stop sign at any intersection arises when the travel on one road approaches traffic-stream density. The function of the sign is to detain a vehicle on the minor road until there occurs in the major traffic-stream a time-gap acceptable for a crossing or merging movement. The stop sign does fix legal responsibility, but it does not confer upon the major stream any immunity from conflict. Many drivers are prone to accept the stop sign as a guarantee that the vehicle on the cross-road will stop. The hospitals, - and cemeteries, - are full of such deluded people.

Since there is no such thing as one-hundred percent observance of any sign, it is vital that adequate clear-vision areas be maintained at all intersections to give drivers on both roads a time-dimension for perception, decision and action.

The Traffic Signal. Under the normal random distribution of traffic, the number of acceptable time-gaps in a traffic-stream decreases very rapidly with increased traffic volumes. When traffic volumes at any intersection are such that the number of vehicles per hour on the cross-road is greater than the number of acceptable time-gaps per hour in the major traffic-stream, the intersection will not function safely or acceptably under stop sign control. A traffic signal is then needed to create artificially the required amount of crossing time.

A traffic signal does not expedite traffic, but neither does it hinder traffic unduly. Its function is simply to allocate time to the intersecting traffic-streams in proportion to their needs, and thus create orderly operation. There are only sixty

COMMENTS

seconds in a minute and therefore there is a limit to the number of vehicles that can be accommodated regardless of the method of control. The signallized intersection does sacrifice a little in capacity but in doing so it promotes order and fixes responsibility.

In a sense, a traffic signal is as undesirable as any other barrier or obstruction in the direct path of the traffic-stream, but for many reasons it must be accepted as a necessary compromise. For one thing, the matter of cost alone prohibits even the thought of universal grade separation. In urban areas, the destruction of property and the consumption of taxable land are convincing arguments against grade separation in all but the most extreme cases.

Traffic signal installation and operation should meet these criteria:

1. Coordination. The location and timing of signals should be integrated to produce and maintain a planned efficient pattern of operation within the area.
2. Visibility. Signals must have high "target value". The operator of a motor-vehicle drives with his eyes, and there is always plenty for those eyes to do without the added burden of spotting obscure signals.
3. Pedestrian usage. It must be remembered that pedestrians need and use the traffic signals. They must be readily visible to the pedestrian, and they must give the pedestrian his fair allocation of crossing time.
4. Amber period. The amber period warns both motorists and pedestrians of impending change of right-of-way. It must be adequate for this purpose, regardless of how much it reduces the net green time per hour. It is the poorest sort of operation to try to boost the capacity of an

overloaded intersection by sacrificing the safety value of an adequate amber.

COMMENTS

The "No Turn" Sign. The presence of a "no turn" sign amounts to a confession of failure to meet that first fundamental requirement of any transportation system, - that it serve the desired movements of traffic directly and conveniently. Furthermore, the prohibition of turns at individual intersections for local or momentary expediency, only serves to shift the desired movement, and the problem, elsewhere. Such haphazard attempts to solve one traffic problem by creating another result in irritation and inconvenience to the traveling public who - after all, are not only the users, but the owners of the transportation system.

The prohibition of left turns is a useful tool, and a perfectly defensible one, when properly used to produce a calculated result. In an area of extreme traffic congestion and reasonably regular street pattern, such as an urban downtown district, prohibition of all left turns will produce an increase in capacity and efficiency approaching one-way operation. Under this system, only clockwise turns are allowed and a left turn is translated into three right turns, or the circling of a block. Thus there is generated a considerable amount of circuitous travel, but the irritation factor is minimized because the requirement is constant and consistent. It is the illogical and unexpected denial of the left turn privilege that irritates drivers.

When left turns are prohibited, the capacity of intersections is greatly increased and traffic operation is simplified. There are no conflicts, and no time-gap requirements other than the crossing time provided by the signal. This system does not insure a clear cross-walk for pedestrians, - neither does it reduce mid-block conflicts in the slightest degree; whereas one-way operation provides both

COMMENTS

of these advantages. Nevertheless, until the simple logic of directionalism begins to be appreciated and practiced, the "no left turn" system of traffic operation is the best compromise for increasing capacity and reducing congestion in areas of high traffic concentration.

PART VI

COMMENTS

THE CAPACITY OF HIGHWAYS AND STREETS

The Highway Research Board has recently published a "Highway Capacity Manual" which represents the final results of more than a decade of research into the fundamentals of traffic operations and highway capacity by some of the most brilliant and thorough minds in the highway field.

The highway engineer has long felt the need for a method of calculating the traffic-carrying ability of a highway with reasonable precision. The need is met by this volume. It is a complete and authoritative text on highway and street traffic, and as such has been accepted and used in the work of the Highway Study Committees of Ohio, New Mexico and other states.

The real value of this manual can be appreciated only by those who have studied it thoroughly, but the following resume may serve to indicate the magnitude of its contribution in the field of highway traffic engineering.

Meaning and Kinds of Capacity

The word "capacity" is a general term pertaining to the ability of a road to carry traffic; it has little meaning unless qualified by the specific kind of road and the specific kind of traffic. The capacity of any road depends entirely upon two sets of conditions:

(1) Those conditions determined by the physical features of the roadway;

(2) Those conditions dependent on the traffic using the roadway.

The former are called the "prevailing roadway conditions." for any specific

COMMENTS

roadway they are fixed, and do not change except by construction or reconstruction of the roadway. The latter are called the "prevailing traffic conditions". They are fluid, and may change from hour-to-hour, day-to-day, or season-to-season.

By definition, there are three levels of capacity; basic, possible and practical.

1. Basic capacity is the maximum traffic volume that could be accommodated if roadway and traffic conditions were ideal. Basic capacity is largely a concept, since ideal conditions do not exist. In certain specific locations however, where roadside interference is eliminated and traffic flow is strictly regimented, basic capacity has been reached for short periods.

2. Possible capacity is the maximum traffic volume that can be realized on any roadway under the prevailing conditions. Possible capacity is real and measurable; it is the volume that cannot be exceeded without changing one or more of the prevailing conditions. It is the condition of congested, overload operation which is typical of many existing streets and highways at peak periods.

3. Practical capacity is the maximum traffic volume that can be accommodated under the prevailing conditions, without undue delay, hazard or restriction of the individual driver's freedom of movement. This qualification is somewhat subjective, but it has been found that satisfactory conditions exist when any roadway is operating at eighty percent of its possible capacity.

Basic Capacity

The basic capacity of a traffic lane is 2000 vehicles per hour. The proof of this is the fact that volumes slightly under this figure have been recorded many times at several locations; whereas volumes slightly in excess of 2000 vehicles in one hour have been recorded only once at each of two locations.

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This basic lane capacity can occur only under ideal conditions; specifically, it can be achieved if and when these five requirements are satisfied:

1. There must be at least two lanes for the exclusive use of traffic in one direction.
2. All vehicles must move at approximately the same speed, and this speed must be between 30 and 40 miles per hour.
3. There can be few commercial vehicles, and no large ones.
4. Width of traffic lanes and shoulders, and clearances from vertical obstructions along the roadway, must be adequate.
5. There must be no sight distance restrictions, steep grades, sharp curves, intersections, driveways, or pedestrian crossings.

Possible Capacity

Possible capacities for different roadway types are derived by discounting the basic capacity according to the conditions prevailing for the roadway under consideration.

A multilane roadway satisfying all of the conditions above would have a possible capacity equal to the basic capacity.

A two-lane roadway, satisfying all of the above conditions other than the first, would have a possible capacity of 2000 vehicles per hour, or 1000 vehicles per lane per hour. Volumes close to this figure actually have been recorded

COMMENTS

frequently, while a volume slightly over 2000 vehicles in one hour has been recorded only once.

A three-lane roadway, under the same conditions, has a possible capacity of 4000 vehicles per hour, regardless of the distribution by direction. No count approaching this figure actually has been recorded for a three-lane road, because there are no existing three-lane roads that meet the sight-distance requirement.

Maximum possible average lane capacities therefore, are:

1000 vehicles per hour for two-lane roads
1333 vehicles per hour for three-lane roads
2000 vehicles per hour for multi-lane roads

The second of the conditions for possible capacity is that all vehicles move at approximately the same speed. This is what most drivers consider to be congestion, when they are restricted and regimented in their movements. Obviously, the practical capacity of a traffic lane is reached when a higher volume will cause unreasonable restriction of movement.

Practical Capacity

The practical capacities for the best modern highways with little or no commercial traffic are:

450 vehicles per lane per hour for two-lane roads
500 vehicles per lane per hour for three-lane roads
1000 vehicles per lane per hour for multi-lane roads

When these figures are further discounted for commercial traffic, inadequate lane or shoulder widths, restrictive lateral clearances, restricted sight distances, excessive grades, intersections and so forth, we arrive at extremely low practical capacities for run-of-the-mill highways. Pedestrian traffic, parking, heavy turning-movements, and cruising traffic further reduce the practical capacities of urban streets. The practical capacity of a downtown city street sixty feet in width, with ten percent commercial traffic, twenty percent turning movements, curb parking on both sides, and a sixty-second light cycle with twenty-seven seconds green, is 1000 vehicles per hour in both directions.

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Essential Information

It should be obvious from the foregoing discussion that generalizations on street and highway capacity can be dangerously misleading. Thorough familiarity with the Highway Capacity Manual and considered judgment in applying the procedures to specific instances are pre-requisite for all technicians whose work involves the design and operation of streets and highways or the control of urban and rural motor-vehicle traffic.

PART VII

COMMENTS

SUMMARY AND CONCLUSION

In the final analysis, traffic is composed of human beings, - not machines; and it is the human limitations that must be considered. We arrive exactly nowhere when we try to analyze the behaviorism of the individual; but by studying the motorist as a genus we can hope to measure his limitations and determine the minimum conditions under which he can function. We know that the motorist's actions are dictated by his brain, on the basis of what his five senses have told him. It is the task of the highway technician to provide optimum conditions for sensory perception, optimum time for mental and physical reaction, and logical uncluttered paths of motion.

Item One is Visibility. Sight is the one sense upon which the "genus motorist" depends above all others; he literally drives with his eyes. Visibility then is the basic criterion, - the first principle, - of road location, road design, traffic control, and traffic regulation. We must see with the driver's eye and from the driver's viewpoint; it is necessary that we make sure that what the driver must see is instantly and constantly visible to him.

Item Two is Time. Time is the basic dimension. In any situation that confronts the motorist, from the simplest to the most complex, the time dimension from point of sight to point of decision must be adequate. It matters little whether or not the motorist knows what he should do, if the road designer or the traffic engineer has not left him enough time to do it. On modern high-speed highways, perception-decision-reaction time converted into feet of travel may be an astonishing distance;

COMMENTS

it behooves the highway technician to arrive at some sound estimates of his time dimensions before they are immobilized in concrete.

Item Three is Dimensional Adequacy. It should hardly be necessary to establish as a principle that any traffic facility should be adequate in cross-sectional dimensions, horizontal and vertical alignment, intersectional design, and traffic control, for the volume and kind of traffic that it will serve. But it is possible that the sincere and impartial application of this principle could result in a complete overhauling of our presently accepted standards of road design, traffic operation, and traffic control. If such be the case, the time for the job is now.

Item Four is Uniformity. The least that the technician can do to help the motorist is to provide him with a norm of operation. When conditions are uniform the motorist can anticipate his actions; his responses are conditioned and therefore faster; he is safer because he has more time for his perception-decision process. There are two things which, for the motorist's sake, should be avoided like the plague; these are (1) unexpected situations with inadequate time-dimensions and (2) obstacles of any nature whatsoever in the direct path of traffic.

Item Five is Simplicity. Simple perception takes less time than multiple perception; simple decisions take less time than complex decisions. When the motorist has only simple decisions to make, logical paths to follow, understandable regulations to follow, and reasonable controls to obey, he has the best chance of operating his vehicle with comfort to himself and safety to others. A bewildered, frustrated, irritated motorist is not a safe person to be guiding a ton-and-a-half projectile on street or highway.

COMMENTS

Item Six is Order. All of these principles operate directly or indirectly toward the creation of order in the movement of traffic. Perfect order in traffic operation would eliminate all accidents and congestion; "it is a consummation devoutly to be wished."

Creating order in traffic operation, as an end in itself, consists of eliminating those existing operational faults which create disorder, chief of which are two-way operation of traffic under traffic-stream densities and the practice of curb-parking. Directionalism in streets and highways, the use of merging and separating lanes, and the separation of grades where warranted, plus coordinated signallization and the elimination of street-parking, are the tools that can bring to our transportation system better than one hundred percent improvement in capacity, efficiency, and safety.

APPENDIX

I. HIGHWAY TRAFFIC AND THE THEORY OF PROBABILITY

(From Technical Report No. 1, Yale Bureau
Highway Traffic, 1947)

When viewed from high above, traffic on a highway gives the appearance of a series of moving dots scattered at random. In general each dot, or vehicle, is quite small compared to its distance from any other vehicle, and each moves independently. Observation shows that different sections of the road of equal length, may contain different numbers of vehicles, and that different numbers of vehicles may pass a given point in different equal intervals of time. The average number of vehicles passing per minute is easily determined by taking the volume of traffic for one hour and dividing it by sixty, but finding the chances that a given number of vehicles will appear in any one particular minute is more difficult. The determination of the chances is mathematically possible by use of the Poisson series relating to probability.

At any moment let a road have vehicles scattered along it at random so that any vehicle is completely independent of any other vehicle, and that equal segments of the road are equally likely to contain the same number of vehicles. These are the conditions for which the Poisson series applies. In England, Mr. W. F. Adams found that free flowing traffic conforms so well to the distribution given by a random series that the latter may be described as "normal".

In order to compare the theoretical distribution of spacings with those actually observed, a table was prepared giving the spacings obtained on four-lane two-directional highways by Mr. O. K. Normann (Results of Highway Capacity Studies, 1942) and those obtained from the Poisson law. The differences between theory and observations are insignificant except for the one-second spacings. Due to the physical lengths of vehicles and the desire of drivers to avoid rear-end collisions, it is obvious that there are, in practice, fewer time-spacings of less than one second than indicated by the Poisson series. Mr. W. F. Adams found that departure from the random distribution due to congestion did not become pronounced until a traffic volume of over 1,000 vehicles per hour per lane was reached. Such a volume is rare.

In contrast to four-lane roads, on two-lane roads except for very light traffic, there is noticeable bunching of vehicles due to inability to pass, with a consequent departure from a theoretical distribution of spacings. In a study of rural traffic conducted in Ohio, it was found that traffic may be considered purely random on a two-lane roadway with volumes not exceeding four hundred vehicles per hour for the two lanes. Above this volume the distribution was found to depart from the random. In general, however, the Poisson series which describes the irregular spacings between vehicles gives results sufficiently accurate to have practical importance. The fact that traffic follows the Poisson distribution makes it possible to apply the theory of probability to the solution of traffic problems that otherwise would be very difficult, if not impossible, to solve.

II. DRIVER & PEDESTRIAN BEHAVIOR

The term "traffic operation" includes the manner of operation of the traffic stream, the individual vehicle, and the pedestrian where he is present in significant volume. Whatever the reason may be, the manner of operation of the traffic-stream as a unit seems to follow the bad habits of individual drivers more readily than the good habits. The faulty operation of the aggregate traffic-stream, such as straddling lane lines, jamming up at railroad crossings, and other "bad manners", reflects individual driver habits.

There are good drivers, average drivers, and bad drivers; with good driving habits, average driving habits, and bad driving habits. No one can say what percentage of drivers falls into any of these categories, but it is beyond argument that the "bad" driver will create disorder while a good driver will not, and that the disorder in the traffic-stream will be proportional to the amount of faulty individual operation.

It follows then that order and orderly traffic movement can be created to the extent that bad driving habits can be regulated or educated into good habits. Driver training, stricter licensing, educational publicity, and selective enforcement are indicated as useful and necessary tools toward the creation of order in the operation of the traffic-stream.

The same observations and conclusions, of course, apply equally to pedestrian traffic where it is of sufficient volume to be a factor in traffic congestion. Although it is true that pedestrians have equal rights to the use of our streets, it is also true that they have equal responsibilities for insuring order and efficiency in the use of them.

A real gain in the order and safety of urban street use could be made if order could be brought into the operation of vehicle and pedestrian traffic-streams, through education of the individual driver and the individual pedestrian.

RELATIVE EFFICIENCY, OPTIMUM WIDTH AND CAPACITY OF CITY STREETS UNDER AVERAGE TRAFFIC CONDITIONS

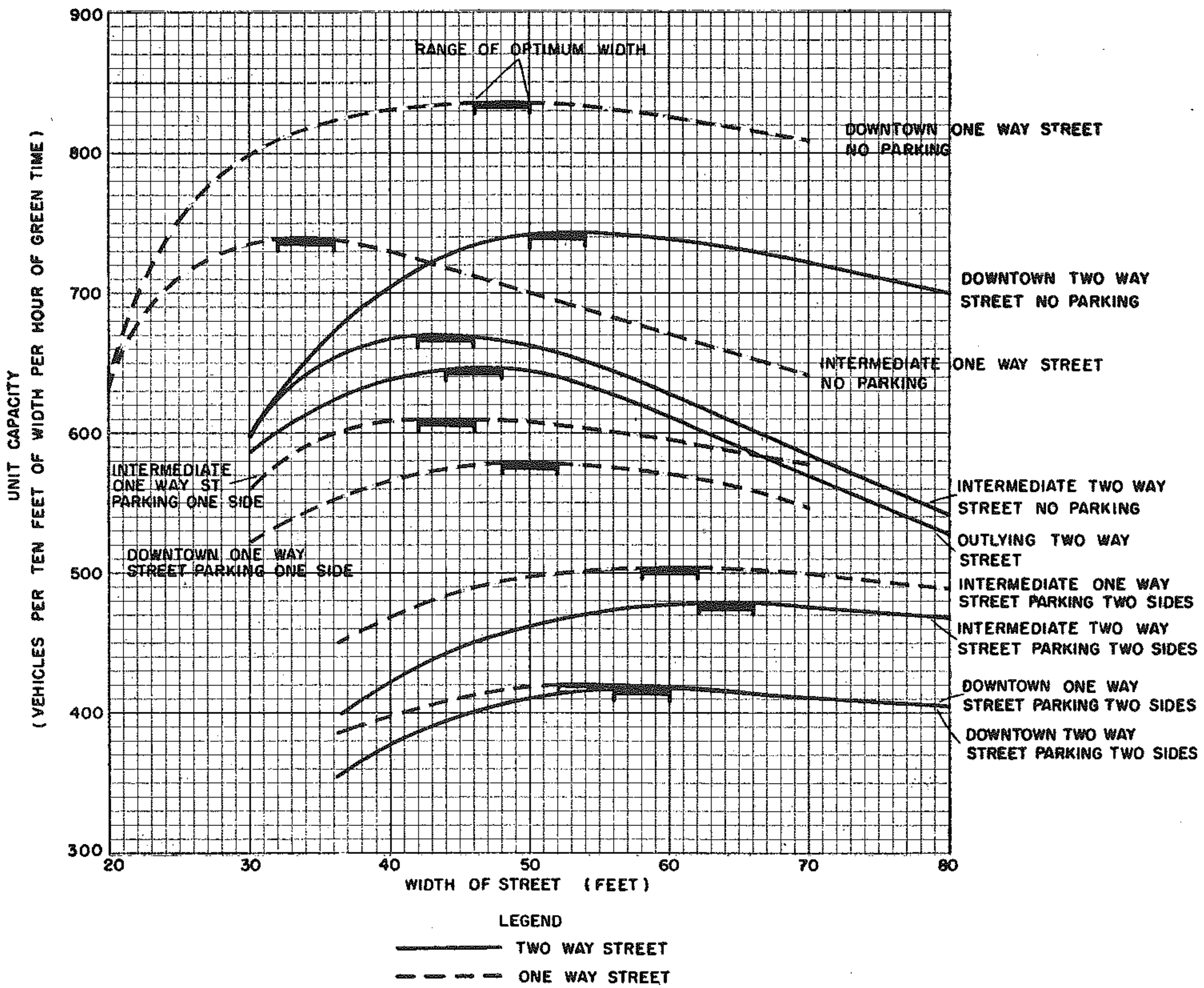
TO USE:

Multiply chart value for given street width by (street width ÷ 10), by (seconds of green ÷ seconds in cycle).

EXAMPLE:

Capacity of 58' street, two way, downtown, no parking; signal 27"g.– 3"a.– 30"r.

$742 \times 5.8 \times \frac{27}{60} = 1936$ vehicles per peak hour both directions. (traffic equally divided by direction.)



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