TRAFFIC MEASUREMENT AND ITS RELATIONSHIP

by

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INTRODUCTION

After World War II, development in highway transportation has brought many serious problems. There has been a tremendous increase in automobile use due to improvement in technology of the automobile industry. An indication of how automobile use is still increasing at a rapid rate is shown by recent auto registration figures. The total passenger car registration in the United States in 1962 was 65,928,547 and it was 68,452,000 in 1963. Also after the war, heavy truck transportation increased. About 75 percent of the nation's total tonnage is hauled by trucks. Truck registration in the United States in 1962 was 13,094,369 and it was 13,606,000 in 1963. The total annual motor vehicle miles of highway travel have increased from about 50,000,000 in 1920 to about 79,800,000,000 in 1963. This great increase in highway traffic in the United States has placed tremendous importance on highway facilities (22).

Traffic congestion is a most important problem confronting highway engineers. The primary cause of congestion is the difficulty in predicting the traffic for the life span of a newly constructed highway. For example, the Pennsylvania Turnpike, which opened in 1939, was over its practical capacity soon after it was opened to traffic. Also there is no universal method which measures the amount of congestion on
the highway. The second most important problem is to calculate the traffic capacity which the highway can carry efficiently. This problem will be studied by this project.

To solve the problem of highway congestion and to calculate efficiently the amount of traffic a highway can carry, traffic factors such as traffic density, traffic volume and mean speed of traffic must be known. Average speed and traffic volume are considered to be inadequate when each is used individually; density, although better than either volume or speed alone, also has shortcomings. For one thing density does not differentiate between commercial and passenger vehicles.

Knowledge of traffic flow characteristics are most essential in measuring highway capacity. During recent years extensive research has been done regarding bunching of vehicles, spot speed distribution and speed delay measurement. The object of this project is to develop a simple method to measure traffic flow, which will contribute to the study of highway capacity. Also it will include suggested procedures utilizing traffic flow in the evaluation of highway capacity.
DISCUSSION OF TRAFFIC FLOW AND HIGHWAY CAPACITY

Traffic Flow Characteristics

The basic features of traffic flow are traffic density, volume of traffic and mean speed of traffic (2). Also elapsed time, distance traveled, speed distribution, acceleration and deceleration rates, fuel consumption and brake utilization are other factors affecting traffic flow. To measure these factors which affect the quality of traffic flow, Michigan State University and the Michigan State Highway Department (25) used a device consisting of 51 counters which automatically record basic characteristics such as speed, fuel, deceleration and acceleration. A master control records the total time in seconds for a particular trip.

Traffic flow has been expressed in terms of a "friction concept" (24)(35). In this concept three frictions, namely intersectional, medial, and marginal can be minimized through proper geometric design, and a fourth friction called internal friction depends on traffic flow. The unstable region of traffic flow is referred to as "critical flow". The characteristics of this type of traffic flow are the appearance of congestion and a drastic reduction in traffic volume and speed. The effect of critical flow spreads very rapidly and becomes dominant over a large area. It has been suggested by Ryan and Breuning (35) that speed, volume and density are
linear within non-critical flow, but that they lose their linearity when the flow becomes unstable. However, this may not be true, as we know that the velocity varies approximately as the square of the spacing of the vehicle. When the velocity increases, the spacing of the vehicle increases, and hence the density decreases.

To understand the conditions affecting traffic flow, many statistical methods, such as probability theory, have been applied to traffic counting (32). Also statistical methods have been used to measure vehicle characteristics such as speed, deceleration, acceleration and fuel economy. These results have been related to traffic flow (6). Both theoretical and experimental work in this area have focused on two major problems. The first of these problems is concerned with the size of the vehicles. The second is the effect of bunching of vehicles in the traffic stream. Poisson's distribution has been used for a theoretical solution of the bunching problem. For the experimental solution, Miller (27) in 1960 proposed a model of traveling queues which took specific account of bunching effect. He found that as the fraction of the constrained vehicles increases, average count in small intervals increases even though the stationary flow rate remains constant.

Herman (20) in his vehicular traffic flow studies, based his observation on "follow-the-leader theory". He found that
a following driver attempts to keep at a minimum the difference in speed between his car and the leading car. In other words, a driver attempts to keep the relative speed between him and the vehicle in the front as small as possible. However, this is not true as we know that driver behavior is not the same for each individual.

Edie and Poote (10) studied traffic flow in tunnels. They found that during rush hours, traffic has to slow down drastically. They also found that at either lower or higher speeds, drivers will space themselves so as to bring a higher headway time and thus lower flow. Using this concept it was proposed that if a platoon of drivers were assembled at random and required to drive at an average speed close to optimum, the length of platoon at any point would indicate roadway capacity. In traversing roads of high capacity at this optimum speed, drivers would drive quite close together and bring about a very low time headway and high maximum flow. This experiment in a Holland tunnel resulted in a six percent increase in hourly flow and provided a more rapid, comfortable and safer traffic movement.

**Bunching of Vehicles**

When the smooth flow of traffic is interrupted by some kind of traffic control device such as signals, the downstream flow of traffic will usually take the form of platoons (15).
Traffic will usually remain in these platoons for some distance down the road, unless there is some kind of interference such as traffic from driveways or intersecting streets either breaking the platoons or filling the gaps between. Studies by the California Highway Department showed that traffic remained in well-defined platoons for distances at least one mile beyond the signal.

It has been found that bunches exist at all levels of traffic concentration and that number and size of these bunches increase as traffic densities increase (3). For measurement of bunching on rural highways, a model analysis has been proposed by Miller (28). Formulas are derived from rate of delay to vehicles on rural roads caused by restricted overtaking. For urban traffic, instead of model analysis, variance/mean ratio of vehicle count provides a useful measure of bunching.

In a statistical method of distribution of cars on highways (19), the distributions are classified as random, regular or equally spaced and intermediate. Random distribution can be represented by Poisson's distribution or by a negative exponential distribution. For distribution of cars, the vehicle counting can be done in two ways: (a) by means of some apparatus which records the time of arrival of each vehicle at fixed point and (b) by some device such as aerial photography which records at a fixed time the spatial arrangement of vehicles.
To measure bunching effect, the headway between two vehicles was measured by the "two-car" method (26). In this method two cars were run on the test section. The rear car was equipped with a Stadimeter (a range finding device) which gave the distance headways between the leading car for different speeds. A digital recording system was installed in the rear car to store all the data. It was found that spacing between vehicles was primarily determined by the driver's reaction to change in speed. Time headways can be calculated from distance headways. Time headways between regular, small and compact vehicles were used to study its effect on maximum traffic flow and highway capacity (11). It was found that drivers of both small and standard vehicles operated in both peak and off-peak traffic in a way similar to the operation of standard cars. So there is no effect on traffic headways or on highway capacity due to small vehicles.

The application of bunching is the evaluation of relative serviceability of two lane highways in non-passing zone area (12). Simply counting the number of vehicles does not solve the problem of traffic congestion. The study has to be extended to determine the relation between bunching and spot speed.

Measurement of Traffic Congestion

Traffic congestion is not a new problem. Back in 1920, cities were trying to evaluate losses due to traffic snarls.
Traffic congestion has a detrimental effect on downtown business activities and property values. It tends to strangle the economic life of communities in cities (14).

According to Rothrock (33), congestion consists of too many vehicles occupying space in a lane of highway for too long a time. The total vehicle time-of-occupancy will increase directly as the volume of traffic increases. However, congestion is a relative thing which varies with size of the city and experiences of the individual. Congestion means more time lost during travel from origin to destination, greater delays in movement of persons and goods, and increased opportunities to be involved in a collision (18).

According to Rothrock (34), to measure congestion, three concepts should be applied, namely, operational characteristics, freedom of movement and volume capacity ratio. But these concepts measure congestion at bottlenecks only because there is no correlation between these three concepts at places other than bottlenecks.

To measure congestion of traffic, Clifford (7) used the method of Greenshield and Easy to measure a congestion index. According to Greenshield (17):

\[ Q = \frac{KS}{\Delta s \sqrt{f}} \]
where \( Q = \text{quality index} \)

\[ S = \text{average speed (miles per hour)} \]
\[ \Delta_s = \text{total mileage in speed per mile} \]
\[ f = \text{frequency of speed change (pure number)} \]
\[ K = \text{constant} = 1000 \]

According to the Easy method (7):

\[ \text{Congestion index} = M_0 = \frac{S}{SR} \]

where \( S = \text{overall speed in miles per hour} \)
\( SR = \text{running speed in miles per hour} \)

If for the study, distance is constant

\[ M_0 = \frac{T_r}{T} \]

where \( T_r = \text{average running time} \)
\( T = \text{average overall time} \)

In designing highways for a certain capacity, congestion indices (34) on a rural highway have been used efficiently. A congestion index is a mathematical rating of highway capacity derived from the ratio of existing hourly volume to the practical capacity of rural highway.

**Traffic Density**

The determination of the effectiveness of traffic control measured at intersections is important from both an operational and research point of view. Solomen (38) used density, vehicle
count and time interval between vehicles for finding the travel time. According to him:

\[ T = \frac{Nt}{V} \]

where \( T \) = average travel time in seconds
\( N \) = total density in vehicles
\( = \) sum of density of vehicles in a given section in certain intervals
\( t \) = interval in seconds between successive density counts
\( V \) = total volume in vehicles for a given time at test section

To measure density in traffic flow, the Automatic Signal Division of Eastern Industries, Norwalk, Connecticut, has developed a "Density Computer" which measures the speed and number of vehicles at a point and automatically counts density in vehicles per mile. This density computer is considered to be very useful for highway capacity studies. Such a density computer has been used by the Washington State Highway Department (42). They have installed this density computer on a 10 mile long arterial highway having 28 signalized intersections. The master signal control consists of six analog computers which receive information from a radar when a vehicle passes underneath it. According to the density in a lane, the traffic signalling is operated. It has been found that this approach
to traffic signalization has totally eliminated the failure which is observed frequently with volume type of traffic actuated signal systems. Also the average vehicular speed has increased approximately 5 to 8 mph. The number of vehicle stoppages at traffic signals has been reduced in excess of 60 percent.

Spot Speed

Spot speed is of utmost importance for highway design. The data for speed is obtained by manual or mechanical methods. Freeborn and Whiting (13) in England used two road tubes stretched 18 feet apart. The time taken by a vehicle to travel this distance is recorded. These time intervals are converted into speed. A similar device was used by Holmes and Reymer (23) in the United States. They used two road tubes 28 feet apart.

The Washington State Highway Department used "traffic detectors" to measure the speed (39)(42). When a vehicle passes underneath a radar vehicle detector, a pulse is transmitted to the master signal control. The radar vehicle detectors themselves transmit a doppler frequency. A direct relationship exists between the speed of the detected vehicle and the doppler frequency. The relationship is in the form of 7.46 cycles per second per mile per hour. This information is sent to the master control which consists of six
analog computers, where it is converted into call rate and an average vehicle speed for some unit of time. The vehicle call rate when divided by the average speed gives the density of the traffic.

The Joint Highway Research Project of Purdue University (1) developed an electronic speedometer which is used with fully charged capacitors. Two pneumatic tubes are stretched 88 feet apart and the capacitors of the speedometer discharge while the vehicle passes through the two pneumatic tubes.

A more recent development in aerial photography, continuous strip stereoscopic photography (43) measures speed and volume together. The equipment consists of an aerial camera in which the film is being exposed continuously by passing through a narrow slit-type aperture. The film velocity is based upon the ground speed of aeroplane and its height above the ground. The film and the image (vehicle) velocities are synchronized so that no image blur occurs. The camera includes two matched lenses with the right lens ahead of the slit and left lens to the rear. Each lens while photographing ground objects continuously exposes only half of the film width. The method is less time consuming, less expensive and is considered accurate.

Travel Time

Because traffic congestion or vehicular delay is a logical factor affecting a new construction program, it is
necessary to measure the degree of congestion. Travel time is one of the most important factors to evaluate in relation to: (a) congestion on urban streets, (b) prediction of traffic diversion and (c) road user benefit analysis. The relation between travel time and density is most useful in estimating travel time.

Several methods such as (a) license plate matching (b) floating car (c) spot speed (d) arrival output volume rate (e) interviews and (f) photographic methods, have been used to measure travel time (41).

To measure travel time in Pennsylvania (8), tape recorders were set up at two points on the test section. They were started simultaneously and the last three digits of license numbers were recorded on tape. Since both recorders were started simultaneously and moving at constant speed, travel time was given by the difference in time recorded at the two points.

According to Sawhill and Firey (37), travel time depends on vehicle characteristics and road characteristics. In flat topography and free moving traffic the travel time is a function of the properly posted speed limit. For trucks on highways, the travel time is given by

\[ T_L = \frac{dL}{52.8 \text{(mph)}_L} \]
where \( T_L \) = travel time in hours

\( dL \) = total length of travel in miles

\((\text{mph})_L\) = speed limit at which travel is done

To determine overall time in urban areas, "floating car" and "average test run" methods have been used (4)(5). In the average test run procedure, the driver is allowed to drive at a speed that in his opinion is representative of speed of all traffic. In the floating car method, the driver is instructed to float with traffic and to pass as many cars as pass him.

North Carolina State University developed the "maximum car method" (9). In this method the car is driven with safety at the posted speed limit unless impeded by actual traffic conditions. The car was equipped with a model-M electronic traffic speed and delay recorder manufactured by the Automatic Signal Division of Eastern Industries in Norwalk, Connecticut. The speed and delay were recorded on a chart running at the same speed of the vehicle. In this test the driver should not be tired and he should not be familiar with physical conditions of the roadway in order to get the true data depending upon vehicle characteristics and roadway characteristics.

In another method called the "moving vehicle" method (29), the car unit 'U' travels a sector of highway under study, the observer records the time to drive the section, the vehicles 'M' moving in the opposite direction and met by the moving
car unit, the vehicles 'O' overtaking the moving car unit, and the vehicles 'P' passed by the moving car unit.

Then,

\[ V = \frac{300(M) + (O - P)}{t} \]

where \( V \) = hourly estimated volume

\[ M = \text{vehicles coming from opposite direction} \]

\[ O = \text{vehicles overtaking the test car} \]

\[ P = \text{vehicles passed by the test car} \]

\[ t = \text{time of test run in hours} \]

Average time required to drive the test section in each direction is given by

\[ t_r = t_1 + t_2 = \frac{O_1 - O_2 - P_1 - P_2}{V} \]

where

\( t_r \) = driving time for round trip in minutes

\( t_1 \) = time of travel for one direction in minutes

\( t_2 \) = time of travel for another direction in minutes

\( O_1 \) & \( O_2 \) = vehicles overtaking the test car in directions 1 & 2 respectively

\( P_1 \) & \( P_2 \) = vehicles passed by the test car in directions 1 & 2 respectively

\( V \) = two directional volume per minute
Highway Capacity

Good forecasts are essential to good planning. Predicting future traffic has been unsuccessful due to short range planning. Planners have always made predictions in a conservative way. They have always underestimated the future needs in order to protect themselves from criticism. For the forecasting of traffic, population growth and vehicle ownership statistics have been used extensively. Arithmetic and geometric projections have been used on such statistics.

In the past, estimates of design hour travel based on traffic count data have been determined by taking a percentage of the estimated average daily traffic. However, there are cases in which the limited capacity of a street or highway has affected the hourly pattern of the traffic. One of the most notable examples is that of the Holland Tunnel in New York City where there is little variation between various hours of the day. Drivers and truckers have adjusted their travel habits to conform to the available capacity of the tunnel (40).

Commercial vehicles reduce both the practical and the possible capacity of a highway. The reason is their large size and low speeds on grades. The low speeds increase the number of passing maneuvers necessary for other vehicles. It has been found that on multilane highways, one commercial
vehicle has approximately the effect of two passenger cars in level terrain and four passenger cars in rolling terrain (30).

To evaluate capacity of highways in mountainous terrain, the West Virginia Highway Department has developed charts of ADT and operating speed. These charts are used to determine the traffic volume the highway will accommodate at a given operating speed (31).

The relation between speed and highway capacity is very important. It has been found that the highest volume per lane occurs on the highways when the vehicles travel between 30 and 40 mph. Any traffic variable or any roadway condition that prevents vehicles from moving safely at a speed of 30 mph lowers the roadway capacity. A traffic density exceeding the critical density is one of these conditions. Prior to development of equipment for traffic studies for the measurement of speed and volume, it was assumed that at some traffic volume below the possible capacity of the highway, a slight increase in traffic volume would cause reduction in the average vehicle speed. If it had been correct, this assumption would have provided an ideal criteria to determine practical capacities (21).

To find the value of the 30th highest hourly volume (commonly used for design purposes) in the investigation of highway capacity, the Danish Highway Authority (44) used a
traffic frequency recorder which records the total traffic flow for each hour. This count was then used to check the capacity of the highway.
PURPOSE AND SCOPE

Purpose

In the evaluation of highway capacity and for the measurement of traffic congestion, spot speed, traffic density and the dependence of bunching upon traffic density are important factors to be known for the following reasons:

(1) There is need for a simple procedure to measure speed, volume, spacing of vehicles, bunching of vehicles, distribution of commercial and passenger traffic, travel time, etc.

(2) Congestion can be easily measured if all the quantities listed above are known.

(3) The procedure should be such that data is obtained readily in the field with minimum and simple equipment, and the data should be capable of being analyzed easily and fast.

(4) Traffic density is considered to be a good factor for measurement of congestion. It has been analyzed and studied before and it serves as a basis for this study.

The purpose of this study is to develop a simple procedure which will measure all the characteristics essential in evaluation of congestion.

Apart from serving as a measurement of congestion, the results of the study may be used in evaluation of highway
capacity by measuring time headways of vehicles and hence the measurement of bunching of the vehicles.

**Scope**

The scope of the study was limited to a few important spots on the Virginia Polytechnic Institute campus where traffic is considerable during rush hours. Observations of traffic count and the velocity of the vehicles were made between 11:45 A.M. and 12:45 P.M. when the major traffic is outgoing. The speed limit on the campus was 25 mph. Seven different locations on the campus were studied.

A simple method which utilized two standard pneumatic tube type traffic counters and a small portable tape recorder was used. The clicking sound of the counters was recorded on tape which was played back through a Brush strip chart recorder in the laboratory.

It is hoped that this simple method and the results obtained will contribute something for the further research in the direction of traffic flow for estimating congestion and in the evaluation of highway capacity.
FIELD TESTS

Development of Equipment

In the past different methods have been used to measure vehicle velocity. Most of the methods are time consuming and expensive.

In an attempt to develop a simple and inexpensive device to measure vehicle velocity, a tape recorder was used in conjunction with two standard pneumatic tube traffic counters. The traffic counters were obtained from the Virginia Department of Highways. High impedance microphones were attached to each of the two traffic counters in a manner enabling them to pick up the clicking noise of the counter being actuated. The microphones were connected by co-axial cable to a portable tape recorder. A portable five-transistor tape recorder with speed of 1 7/8 ips was used and was operated with two C-type batteries and one nine volt battery.

After recording in the field, the tape recorder was taken into the laboratory and played through Brush strip chart recorder equipment (Brush Development Co., Cleveland, Ohio). The chart recorder was operated at a speed of one foot per minute, with one division on the chart representing one second.

In order to check the accuracy of recording, time intervals were recorded on tape and were noted by use of a
stop watch. It was found that accuracy was within an acceptable range. In order to eliminate the effect of run-down batteries on the speed of the tape recorder, fresh batteries were used for each experiment, both in the field and in the laboratory.

To check the accuracy in the field, a vehicle was run at different speeds. The time intervals to cross the two pneumatic tubes were noted using a stop watch. The time intervals noted with the stop watch and recorded by tape were found to be in almost perfect agreement.

Traffic Flow Measurement

The distribution of spot speed and amount of bunching on two lane highways are affected by the following factors:

(1) **Geometric Features** of roadway such as grade, sight distance, curvature, etc.

(2) **Traffic Factors** such as traffic density, commercial traffic, parking conditions, volume of pedestrians, etc.

(3) **Miscellaneous Conditions** such as weather, speed limit, traffic controls, etc.

Since the purpose of this study was to find the usefulness of the simple method just described to measure velocity, all factors listed above could be variables. But if traffic density were the only variable, sites could be selected so
that all factors such as geometric features, traffic factors and miscellaneous factors were eliminated or minimized.

The following locations were selected on the V.P.I. campus for the data collection:

(1) Price's Fork Road near Golf Course
(2) North side of Mall near Student Activity Building
(3) South side of Mall near Student Activity Building
(4) McGill House
(5) Washington Street near Coliseum
(6) Kent Street near University Club
(7) V.P.I. Power House

The data were collected in clear weather with good visibility all within a three-month period between March and May 1964. There were no traffic controls except that at McGill House and North and South side of the Mall traffic was one-way. Commercial traffic was practically nil. The topography of the campus does not have significant effect on the traffic.

Data Collection

The pneumatic tubes of the two traffic counters were placed 30 feet apart. Microphones and the tape recorder were connected with proper care. The existing value on the traffic counter was noted and the tape recorder was started. The time of data collection was noted. After the tape was completed, the time and the traffic counter value were noted.
Each side of the tape was able to record for about 25 minutes. Vehicles, when crossing the tube, produced a click in the counter which was recorded on the tape. Thus each vehicle crossing the tube produced four clicks. If two vehicles crossed the tubes at about the same time, it was difficult to distinguish their clicks on the tape. Figure 1 shows diagrammatically the connections and the relative position of the equipment.

Data did not have to be recorded manually in the field except for noting time and traffic counter readings at the beginning and at the end of the tape. Only one man was needed to obtain all the data in the field.

Processing of Data

In the laboratory, five minute intervals were marked off on the tape and the number of the vehicles were counted for the interval. Then the time intervals for the vehicles to cross the tubes and hence the velocity for each vehicle was calculated. Average velocity for each five minute group and the standard deviations of velocities between vehicles of each group and between each group were calculated. The lane density in vehicle per minute was calculated for each group. Also the time headways between each vehicle in the group were calculated and percentages of vehicles travelling closer than a specified headway were calculated.
**FIELD ARRANGEMENT**

![Diagram showing field arrangement](image)

**LABORATORY ARRANGEMENT**

![Diagram showing laboratory arrangement](image)

**FIGURE - 1** DIAGRAM SHOWING ARRANGEMENT AND CONNECTIONS OF THE EQUIPMENT
RESULTS

Tables 1 through 4 and Figures 2 through 4 present the basic results of this project. Table 1 presents volume, average lane density, average speed and standard deviation of speed for each location. Table 2 presents the increase in traffic on the campus in the last two years. Table 3 presents the percentage of vehicles travelling closer than specified headways at different locations. Table 4 presents the data obtained in the field for checking the accuracy of the equipment. Figure 2 shows the relationship of average lane density and standard deviation for the locations. Figure 3 shows the relationship between average speed and standard deviation. All the straight lines in these figures and their correlation coefficients were obtained by the method of "least squares."

The density in vehicle per minute for each group was calculated as

\[ D = \frac{V}{t} \]

where \( V \) = total volume of vehicles in time \( t \) (min)

\( t \) = time for traffic collection in minutes.

The speed for each vehicle was determined from the measured time interval on the tape as
\[ s = \frac{\text{Distance}}{t} \]

where Distance = 30 feet

\[ t = \text{time interval in seconds on tape} \]

\[ S = \text{velocity in ft/sec} \]

If \( S \) is measured in miles per hour, then

\[ S = \frac{30}{1.47t} = 20.45 \]
<table>
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<th>Location</th>
<th>5-min. Volume</th>
<th>Average lane density (VPM)</th>
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Table 2. Virginia Polytechnic Institute Traffic Data of the Campus

Time of Collection: 11:45 A.M. to 12:45 P.M.

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<td>(3) Washington &amp; Kent Street</td>
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</tr>
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<td>---</td>
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<td>---</td>
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<td>70</td>
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<td>North side</td>
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<td>---</td>
<td>42</td>
</tr>
<tr>
<td>South side</td>
<td>---</td>
<td>---</td>
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<tr>
<td>(7) Golf Course</td>
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### Table 3. Percentage of Vehicles Travelling Closer Than Specified Headway

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Table 4. Checking Accuracy of Equipment in Field

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<th>Travel Time Stop Watch secs.</th>
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<td>34.10</td>
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Figure 2: Relationship between average lane density and standard deviation.
Figure 3: Relationship between average lane density and average speed
Figure 4 Relationship between average speed and standard deviation

- ○ GOLF COURSE
- X NORTH SIDE MALL
- △ SOUTH SIDE MALL
- □ MCGILL HOUSE
- ● WASHINGTON STREET
- (+) KENT STREET
- ○ ($$) POWER HOUSE

AVERAGE SPEED (MPH)

STANDARD DEVIATION (MPH)

$r = 0.162$
DISCUSSION OF RESULTS

The graphs of average lane density vs average speed and average lane density vs standard deviation of velocity had correlation coefficients of -0.435 and -0.412. The correlation coefficient between average speed and standard deviation of velocity had a very low value of 0.162.

It was found that standard deviation of 3.45 between velocities was highest near the Golf Course. This was probably due to cars coming on a down grade from the student parking lot. The lowest value of standard deviation of velocity was near McGill House where there was high lane density during rush hours.

The time headways between vehicles were calculated only for McGill House and the Mall where the traffic was in one direction. It was found that all vehicles on the Mall were travelling at an interval more than 10 seconds as the lane density was very low. The headways near McGill House varied from less than one second up to 10 seconds. During peak hour, most of the vehicles were travelling at headways of less than two seconds.

Maximum average speed of 29.21 mph was recorded near the Golf Course which was probably due to down grade of the roadway. Minimum average speed of 15.44 was found near McGill House where traffic density was the heaviest.
It is believed that for roads of higher volume, the correlation between standard deviation and lane density, average speed and lane density and standard deviation and velocity would be much greater. The data merely shows that even during rush hours the campus roads are not carrying much traffic. Five hundred twenty-eight vph at McGill House is not a large peak hour volume for a two-lane, one-way street.

The results of the field speed check show that the equipment is accurate. The only doubt concerning the equipment is the unusual effect on traffic. In some instances, the traffic upon sighting the road tubes will tend to slow down. However, in the campus situation described here, this effect is thought to be negligible. Also, public recognition of traffic counting tubes is thought to make the usual slow down effect low. Only the pneumatic tubes are in prominent sight as the other equipment is small and can be easily hidden. However, it is important for the operator to remain out of sight.

From Table 2, it has been found that the traffic at McGill House has decreased in the last two years. This is because it used to be a two-way street. The traffic on the campus has been increasing every year. However, from Table 2 it is found that the traffic count at different locations is almost the same due to new traffic regulations.
It is believed that it is possible to differentiate commercial and passenger vehicles. The different number of axles and their lengths can be determined from the tape after determining the velocity of the vehicles. The time interval for the axles of the vehicle to cross the pneumatic tube is measured from the tape. Knowing the time interval and velocity of the vehicle the distance between the axles can be found.
CONCLUSION AND RECOMMENDATIONS

The results of the experiment and its analysis can be summarized as follows:

(1) It was found that the velocity measured by this equipment gives accurate results.
(2) By this method the speed and volume of the traffic can be measured together at the same time.
(3) From the results obtained for the data collection, it was found that as density increases, the average speed of the traffic in general decreases.
(4) With high lane density, headway between the vehicles decreases.
(5) There is a possibility of differentiating commercial and passenger vehicles from their axle lengths which can be recorded on the tape.

Recommendations

During the data collection, it was found that the clicks do not differentiate the vehicles coming from the opposite direction. It is believed that if one of the microphones had a higher sensitivity than the other, it would record the click with a larger blip on the chart.

The following recommendations may be useful for further research in traffic flow measurement:
(1) In order to get more accurate results for longer periods, a good tape recorder having good accuracy should be used.

(2) If tape recorder is used with batteries, they should be fresh every time to get accurate results.

(3) Each microphone should have different sensitivity so that they can differentiate the traffic in two directions.
BIBLIOGRAPHY


42. Washington State Highway Department. Special information by correspondence.


ACKNOWLEDGMENT

The author wishes to express his indebtedness and gratitude to Dr. R. D. Walker, head of thesis committee, for his deep interest, patient encouragement, guidance and assistance during the course of investigation, and for many valuable suggestions in preparing this thesis.

Gratitude is also due to Dr. H. M. Morris, head of the Civil Engineering Department, for making possible for the author to pursue his graduate studies. The author also acknowledges his gratitude for Dr. Morris' keen interest and continuous spiritual inspiration.

Sincere gratitude is due to the author's parents, Mr. and Mrs. R. M. Shah, and to his wife, Urmila, whose sacrifice and encouragement made possible the author's study in the United States.

Finally a debt of gratitude is extended to Mrs. R. D. Walker for a very neat and accurate typing of the thesis in such a short time.
The vita has been removed from the scanned document
Abstract

TRAFFIC MEASUREMENT AND ITS RELATIONSHIP

Measurement of traffic congestion and evaluation of highway capacity has become an important topic. Highway capacity depends on the operating speed of the traffic and the spacing of vehicles.

The purpose of this thesis is two-fold:

(a) to find a simple and inexpensive method which can measure both the speed and volume of traffic together, and

(b) to use the analysis of the data collected in evaluating highway capacity.

It is believed that the simple method developed would be able to differentiate between commercial and passenger traffic.

The method used consisted of two standard pneumatic road tubes and a portable tape recorder. The clicking sounds of the traffic counters were recorded on the tape which was analysed in the laboratory.

The average speed of the traffic depends on lane density, provided all other factors such as geometric features of the roadway, traffic factors and miscellaneous conditions remain constant. At higher density, the standard deviation of velocities of vehicles drops off. Also at higher density, vehicles travel much closer for a given velocity. From
headway determination of vehicles, it is possible to analyze bunching characteristics of the traffic.

It was found that the traffic on the V.P.I. campus is increasing every year. Still, the roads of the campus are not running over capacity.

The procedure developed in this study proved to be of sufficient accuracy to be useful in further research of traffic flow.