



Scholars' Mine

Masters Theses

Student Theses and Dissertations

Spring 1971

A digital computer simulation of a rural two-lane highway

D. Jay Frankenfield

Follow this and additional works at: https://scholarsmine.mst.edu/masters_theses

 Part of the [Civil Engineering Commons](#)

Department:

Recommended Citation

Frankenfield, D. Jay, "A digital computer simulation of a rural two-lane highway" (1971). *Masters Theses*. 7226.

https://scholarsmine.mst.edu/masters_theses/7226

This thesis is brought to you by Scholars' Mine, a service of the Missouri S&T Library and Learning Resources. This work is protected by U. S. Copyright Law. Unauthorized use including reproduction for redistribution requires the permission of the copyright holder. For more information, please contact scholarsmine@mst.edu.

User's Guide for:

A DIGITAL COMPUTER SIMULATION OF A
RURAL TWO-LANE HIGHWAY

by

D. Jay Frankenfield

This traffic flow model is a digital computer simulation utilizing the technique of periodic scanning to move the vehicles through a series of unit blocks. The model simulates traffic flow on a rural two-lane highway by assuming a straight and level road and incorporating sight distance restrictions and no-passing zones to simulate the effect of limited sight distance.

- I. Vehicle information is assigned by a separate vehicle data preparation program. By assigning VPH = desired traffic volume in vehicles per hour, a selected traffic volume may be simulated. Output from the vehicle data preparation program is punched onto cards to be read into the simulation program.
- II. To incorporate no-passing zones into the model, place the no-passing zone input packet directly behind the statement 40 CONTINUE. If this addition is not made, the program assumes a straight road with unlimited sight distance.
- III. Five different passing rules may be simulated by using one of the five \$PASS subroutines. These five passing rules are:
 1. Pass only when safe to pass,
 2. Pass everytime,
 3. Acceptable gap = 1000',
 4. Acceptable gap = 1000 + 1000 * RAND(0),
 5. Accept gaps according to the Cassel and Janoff criteria.

IV. If no-passing zones are not used in the model, the data deck for the simulation program is just the vehicle data deck prepared by the vehicle data preparation program. However, if no-passing zones are used in the model, a no-passing zone data deck must be placed behind the vehicle data deck in order to complete the data deck for the simulation program.

No-passing zone data decks for 34% and 67% no-passing zones are furnished with the program. These no-passing zone configurations were taken directly from log-mile records of no-passing zones on two highways in the Missouri primary system.

NOTE:

For further details in the operation of this simulation program consult-

"A DIGITAL COMPUTER SIMULATION OF A
RURAL TWO-LANE HIGHWAY"

by

D. Jay Frankenfield

Master's Thesis UMR
Spring 1971

A DIGITAL COMPUTER SIMULATION
OF A RURAL TWO-LANE HIGHWAY

BY

D. JAY FRANKENFIELD, 1948-

A THESIS

Presented to the Faculty of the Graduate School of the
UNIVERSITY OF MISSOURI-ROLLA

In Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE IN CIVIL ENGINEERING

1971

Approved by

James L. Jacoby (Advisor)

Frank A. Gerig Jr.

Frank J. Kern

ABSTRACT

The traffic flow model developed in this study is a digital computer simulation utilizing the technique of periodic scanning to move the vehicles through a series of unit blocks. The model simulates traffic flow on a rural two-lane highway by assuming a straight and level road and incorporating sight distance restrictions and no-passing zones to simulate the effect of limited sight distance.

By utilizing various "passing rules" to initiate the passing maneuver, three general topics were investigated. This study investigated the use of 1000 ADT as a criterion for yellow line striping no-passing by using the computer simulation to determine at what traffic volume a significant number of potential passing conflicts begin to occur. The "pass only when safe to pass" passing rule was used to determine the relationship between the passing maneuver and traffic volume when the effect of human error was removed. By using various values for gap acceptance in the computer model, it was possible to determine if gap acceptance is a significant factor in the overall flow characteristics of a two-lane highway.

The results of the research indicated that: (1) 1000 ADT is a reasonable criterion for striping no-passing zones. (2) if vehicles attempt to pass only when it is safe to pass, the maximum number of passes per mile per hour occurs when traffic volumes reach the region of 800 vehicles per

hour, and (3) gap acceptance is a significant factor in the overall flow characteristics of a two-lane highway.

ACKNOWLEDGMENTS

The author wishes to express appreciation to the members of his graduate committee, Dr. Frank A. Gerig and Frank J. Kern, for their numerous and significant contributions to this research effort. Special appreciation is extended to his faculty advisor, Dr. James L. Josey, for his guidance and advice. Without his aid and constructive criticism, this thesis would not have been possible.

Especially to be noted is the contribution of my wife, Janis. Without her encouragement, perseverance, and typing this thesis would not have been completed.

Finally, sincere thanks are extended to my parents, Dr. and Mrs. L. W. Frankenfield, for their guidance and support in earlier years.

TABLE OF CONTENTS

	Page
ABSTRACT . . . . .	.ii
ACKNOWLEDGEMENT	iv
LIST OF ILLUSTRATIONS . . . . .	.vii
LIST OF TABLES . . . . .	.viii
I. INTRODUCTION	1
A. The Problem	1
B. Technique	3
C. Objectives	5
II. REVIEW OF LITERATURE . . . . .	.7
A. Overtaking and Passing Characteristics . . . . .	.7
B. Use of Computer Simulations in Studying Transportation Problems . . . . .	.10
III. DESCRIPTION OF THE MODEL	12
A. General Description . . . . .	.12
B. Input - The Data Preparation Programs . . . . .	.14
C. Main Program	19
D. \$PASS . . . . .	.23
E. PASSR and PASSL . . . . .	.25
F. Explanation of Output . . . . .	.28
IV. RESULTS AND DISCUSSION	30
A. Pass Everytime	30
B. Pass Only When Safe to Pass . . . . .	.32
C. Effect of Various Gap Acceptance Criteria	34

Table of Contents (continued)	Page
V. CONCLUSIONS AND RECOMMENDATIONS . . . . .	.49
A. Conclusions . . . . .	.49
B. Recommendations For Further Research	50
BIBLIOGRAPHY . . . . .	.52
VITA . . . . .	.56

LIST OF ILLUSTRATIONS

Figure	Page
3.1. Cumulative Speed Distribution	17
4.1. Traffic Volume vs. Number of Attempted Passes and Traffic Volume vs. Number of Emergency Indicators for Low Traffic Volumes when the "Pass Everytime" Passing Rule is Used.	43
4.2. Traffic Volume vs. Number of Attempted Passes for Simulation Runs Using the "Pass Everytime" Passing Rule	44
4.3. Traffic Volume vs. Number of Emergency Indicators for Simulation Runs Using the "Pass Everytime" Passing Rule	45
4.4. Traffic Volume vs. Number of Passes for Simulation Runs Using the "Pass Only When Safe to Pass" Passing Rule	46
4.5. Traffic Volume vs. Total Delay Time for Simulation Runs Using the "Pass Only When Safe to Pass" Passing Rule	47
4.6. Gap Acceptance Criteria	48

LIST OF TABLES

Table	Page
4.1. Output from Simulation Runs Using the "Pass Everytime" Passing Rule	38
4.2. Output from Simulation Runs Using the "Pass Only When Safe to Pass" Passing Rule	39
4.3. Output from Simulation Runs Using the "Accept 1000 Feet" Gap Acceptance Criterion . . .	40
4.4. Output from Simulation Runs Using Gap Acceptance Criteria Similar to that Used by Cassel and Janoff	41
4.5. Output from Simulation Runs Using the "Accept 1000 + 1000*RAND (0)" Gap Acceptance Criteria	42

I. INTRODUCTION

A. The Problem

"The pursuit of happiness in America grows more and more dependent upon transportation (1)." To the majority of people the term transportation first brings to mind the highway mode of transport. There are more than three million miles of rural roads and city streets in the United States with the rural roads carrying well over ninety percent of the estimated intercity traffic (1).

Today the present interest in highways usually centers around freeways, expressways and the interstate system. However, "at least ninety percent of the total rural mileage is of the two-lane type and much of this mileage was constructed before modern geometric design standards were established (2)." Lane for lane, two-lane highways have substantially less traffic carrying capacity than the four-lane divided highway. The levels of service achieved by two-lane highways only approach that of the four-lane highway when unlimited sight distance is available. But, on many existing highways the geometric configuration of the roadway restricts the available sight distance. On these roads, the limited availability of adequate sight distance, as well as the presence of oncoming traffic, limits the number of acceptable passing opportunities. Two-lane roadways also compare unfavorably with four-lane divided facilities in terms of safety. "Recent investigations of

highway safety have shown that the death rate on two-lane rural highways is more than twice as great as on limited access rural highways (3)."

Safely executing the overtaking and passing maneuver required on a two-lane highway "necessitates correct judgment of many variables. The speed of the passed vehicle, the speed of an oncoming vehicle, the distance required to pass, and the correct estimation of available passing distance must all be assessed by the driver (4)." Presently, the primary aid available to a driver attempting a passing maneuver on a two-lane highway is the yellow line striping of no-passing zones. The Missouri State Highway Department is currently using a value of 1000 ADT as a criterion for striping no-passing zones on rural two-lane highways. Because striping is a large Highway Department budget item, as well as a valuable driver's aid, it is worth while to determine if this use of 1000 ADT as a criterion is a reasonable practice. By using a digital computer model simulating a two-lane highway, it is possible to determine at what traffic volume a significant number of potential passing conflicts begin to arise.

Numerous studies have been made concerning the passing maneuver and traffic flow on two-lane highways. O. K. Norman (5) did observational studies in the early 1940's that have become the basis for the present American Association of State Highway Officials (AASHO) design standards. Recent emphasis in research for two-lane highways has been

concerned with the feasibility of electronic remedial aid systems to advise the driver attempting a passing maneuver (6). However, for effective analysis it is necessary to learn more about the relationship between the passing maneuver and traffic flow on rural two-lane highways. The output from a digital computer model of a two-lane highway provides the data necessary to depict graphically many relationships between the passing maneuver and traffic flow including the relationship between attempted passes, potential conflicts and traffic volume.

In studying traffic flow on two-lane highways, one of the problems that develops is the proper modeling of the gap acceptance procedure. Gap acceptance refers to a driver's decision to determine if the gap between him and the closest oncoming vehicle in the opposite lane is sufficient to initiate a passing maneuver. Although studies have been made to determine a practical method of modeling gap acceptance (7), it is not known if gap acceptance is a critical factor in controlling traffic flow on a two-lane highway. By using various values for gap acceptance in a computer model, it is possible to determine if gap acceptance is a significant factor in passing studies.

B. Technique

The technique of computer simulation is the primary tool used in this study. Simulation has been defined as "dynamic representation achieved by building a model and moving it through time (8)." The technique of simulation

has long been an important tool for engineers. Early uses of simulation included scale models of structural and hydraulic systems, wind tunnel simulations and the simulation of lines of communication by an organization chart. With the advent of high speed digital computers, simulation techniques have taken on added importance (9).

In recent years, computer simulation of real systems has become a valuable tool for decision makers in many fields. These fields of application include transportation, management systems, space technology, economics and military operations. Because computer simulation techniques permit the study of complex systems under controlled laboratory conditions rather than under the adverse and uncontrolled conditions of the real system, this technique has been becoming increasingly popular (10).

In developing a simulation model of any real system, the five following steps are generally followed:

1. Define the problem and set specific objectives.
2. Formulate the model.
3. Prepare a computer program to implement the model.
4. Conduct experimental runs of the simulated system.
5. Interpret the results or output from the simulation runs (11).

It is necessary to develop some procedure for scanning when developing a digital computer model. This scanning procedure is necessary because the digital computer cannot examine all parts of the system simultaneously, and because

the digital computer must divide time into discrete elements. There are two general methods of scanning. Periodic scanning consists of periodically scanning and updating the entire system after each time interval scanned. The other method of scanning is event scanning. This method consists of determining what significant event will happen next and advancing the clock to the time of that event. Periodic scanning is usually the most straight forward method, while the event scanning procedure may result in a savings of computer time (11).

For this study, the method of periodic scanning was utilized in moving the simulated vehicles through a series of unit blocks. A unit block was used to represent a certain length of a two-lane highway. This methodology resulted in a simulation model that was reasonably straight forward and easy to understand. Yet, the model did not require an excessive amount of computer time.

C. Objectives

As part of the interdisciplinary studies of the Transportation Institute, the specific aim of this research was to achieve the following objectives through the formulation and development of a digital computer simulation of a rural two-lane highway.

1. Investigate the use of 1000 ADT as a criterion for striping no-passing zones by determining at what traffic volume a significant number of potential passing conflicts begin to occur.

2. Fit curves to express the number of attempted passes and the number of emergency indicators as a function of traffic volume when vehicles attempt to pass everytime a passing situation occurs.
3. Determine the relationship between the number of passes, the amount of delay time and traffic volume when vehicles attempt to pass only when it is safe to pass.
4. Determine if gap acceptance is a significant factor in the overall flow characteristics of a two-lane highway by comparing the output from computer simulation runs using selected gap acceptance criteria.

II. REVIEW OF THE LITERATURE

A. Overtaking and Passing Characteristics

Proper modeling of the overtaking and passing maneuver is essential for simulating a rural two-lane highway. Much of the available information concerning the passing maneuver was developed in determining proper geometric designs to provide the required safe passing sight distance (12, 13). AASHO has attempted to incorporate human factors into the standards for required passing sight distance by observing the passing practices of many drivers. These AASHO design standards were based on the driver's behavior in an appreciable percentage of the observations and assumed that during the passing maneuver, the passing vehicle averaged 10 mph faster than the vehicle being passed. The original standards were established in 1939, and another study in 1957 concluded that there were not significant changes in passing practices to warrant changing the standards (12).

A probabilistic approach was taken by Matson, Smith and Hurd (13) in relating the overtaking and passing maneuver to the overall vehicle flow characteristics for a two-lane highway. They developed a curve showing the relationship between the number of passes per mile per hour required to maintain desired speed and the traffic volume. They also compared the number of passes required to maintain desired speed to the actual number of observed passes recorded by O. K. Norman (5) for various traffic volumes.

Many studies have been made to observe driver characteristics and judgement in the passing situation. Jones and Heimstra (14) studied the ability of drivers to make critical passing judgements by measuring drivers ability "to estimate the last safe moment for passing." They determined that drivers could make an estimate of closure time "with a relatively high degree of accuracy." However, when asked to estimate the last safe moment to pass, drivers made unsafe underestimates approximately 50 percent of the time. In addition, Gordon and Mast (15) concluded that "drivers were unable to estimate overtaking and passing distances accurately," and the unsafe "error of underestimation increased with speed." They recommended the following driver aids:

1. Passing areas and "no passing" signs (traditional aids to overtaking and passing).
2. Speed limits and other speed regulations particularly in passing zones.
3. Driver education not to pass at high speeds and to cooperate with the overtaking driver.
4. Road design modification, such as wide shoulders and addition of lanes.
5. Traffic planning to minimize use of two-lane rural roads.
6. Electronic devices informing the driver when it is safe to pass.

Farber and Silver of the Franklin Institute Research Laboratories made a series of studies concerning driver judgement and the passing maneuver (16, 17, 18). These studies were made to investigate the possible use of remedial aids in various passing situations. They concluded

that providing information to the driver concerning on-coming car speed and closure rate should improve safety and overall traffic flow on two-lane highways. Additionally, a more comprehensive study was made by another Franklin Institute Research Laboratories (FIRL) team under the direction of Anno Cassel (6). This very detailed and thorough study of remedial aid systems for the passing maneuver concluded that an economically feasible electronic system of driver aid could be developed and implemented. However, the FIRL report also stated that more accurate and detailed studies are needed.

A Texas Transportation Institute, Texas Highway Department Cooperative Research report by Weaver and Glennon (19) studied the "passing maneuver as it relates to the passing sight distance standards." Their report was "an examination of current state of knowledge concerning the passing maneuvers to ascertain the validity of existing passing sight distance standards." They concluded that several values used in current AASHO design standards are questionable. These questionable values included the striping specifications first developed in the 1940 AASHO Policy for striping no-passing zones.

A report by Valkenburg and Michael (2) presented at the 1971 Annual Meeting of the Highway Research Board compared the use of the short zone and the long zone concept for marking no-passing zones on two-lane highways. This investigation carefully studied the passing maneuver to

determine the desirability of using the long zone concept. The report concluded that the long zone concept of marking no-passing zones was superior to the short zone concept.

These studies concerning the characteristics of overtaking and passing maneuvers show the wide spectrum of problems related to this maneuver and the present state of the art in applying solutions. An examination of the studies will also show the need for more information since many questions remain unanswered.

B. Use of Computer Simulations in Studying Transportation Problems

Computer simulation of real systems has become a valuable aid to analysts and decision makers in many disciplines in recent years. In the area of Transportation, computer simulation has been the major tool in many successful studies. A computer simulation was used to model a two-lane rural road in a study of the effectiveness of remedial devices by Cassel and Janoff of the Franklin Institute Research Laboratory (20, 6). This model included a sophisticated handling of the passing maneuver making it a relatively advanced model of the two-lane rural road. Another less sophisticated mathematical model was developed by Erlander (21) to study traffic flow characteristics on a two-lane highway. In a study entitled "A Digital Simulation of Car Following and Overtaking" by Fox and Lehman (22), a computer simulation was used to incorporate human factor concepts into the car following equation.

Dawson and Michael (23) used a computer simulation model of a freeway on-ramp to study the flow characteristics for various ramp and freeway volumes. A multipurpose model was developed to describe traffic performance and control at individual intersections in a comprehensive study entitled "Improved Criteria for Traffic Signals at Individual Intersections" by Gerlough and Roland (24). These recent studies are typical of the wide variety of transportation problems which have been successfully completed with the computer simulation technique.

The advantage of computer simulation for research in transportation systems has been epitomized in the statement made by Hiller and Lieberman (9) to the effect that "the experiments are done on the computer model rather than on the real system because the latter would be too inconvenient, expensive and time consuming."

III. DESCRIPTION OF THE MODEL

A. General Description

The traffic flow model used in this study is a digital computer simulation utilizing the technique of periodic scanning to move the vehicles through a series of unit blocks. The simulation program is written in Fortran IV computer language, and all simulation runs were made on an IBM 360/50 computer located on The University of Missouri-Rolla campus.

The model was developed to simulate traffic flow on rural two-lane highways and does not include any provisions to simulate intersecting routes at grade or interchanges. The basic model simulates traffic flow on a straight and level road carrying various traffic volumes. However, by incorporating sight distance restrictions and no-passing zones the model can simulate roads with various geometric configurations. Slow down factors could also be added to simulate the effect of hills and horizontal curves.

Four miles of road were simulated in this model. However, data was recorded only on the middle three miles to avoid difficulties normally encountered in modeling end conditions. The distribution and configuration of sight distance restrictions and no-passing zones were taken directly from existing roads in Missouri. This road information, as well as the vehicle speed distribution, was furnished by the Missouri State Highway Commission.

Vehicles are introduced into the system at each end according to a predetermined modified Poisson headway distribution (25). When using a true Poisson distribution, time between arrivals is expressed as an exponential curve. However, in this simulation the exponential curve was shifted a small amount away from the origin to eliminate less than minimum headways and to insure that only one vehicle entered the system during any one interval of time. Desired speeds for vehicles entering the system were determined from observed speed distributions on ten rural highways in the Missouri primary system (26).

Road configuration and vehicle information were assigned by separate data preparation programs prior to running the simulation program.

In this model, a passing situation arises when a vehicle is constrained or will be constrained in the next time interval to travel at a speed less than its desired speed because of a leading vehicle traveling in the same lane at a lower speed. When this passing situation occurs, the decision as to whether to initiate the passing maneuver or to decrease speed and assume a safe following distance is made by a subroutine called \$PASS. Many different passing rules may be simulated by altering subroutine \$PASS. Once the decision to pass has been made, the passing vehicle is advanced through the passing maneuver by the subroutine PASSR for vehicles in the right lane and subroutine PASSL for vehicles in the left lane. These

two subroutines accelerate the passing vehicle at its individual acceleration rate until the passing vehicle is traveling ten miles per hour faster than the vehicle being passed. After this ten mile per hour speed differential has been established, the passing vehicle travels at a constant speed until the pass is completed. If the passing vehicle is unable to complete the attempted pass safely, the subroutine will simulate acceleration or deceleration of the vehicle to avoid an accident. An emergency indicator is recorded when such evasive action is taken.

B. Input - The Data Preparation Programs

There are two data preparation programs. The first of these programs assigns the initial values to the vehicle data matrix $VEH(I,J)$, where I equals the vehicle identification number, and J indicates a particular piece of information about vehicle I.

Input for this vehicle data preparation program consists of six cards which state desired traffic volume in vehicles per hour, the simulation distance, the approximate average velocity of the input vehicles, the deceleration rate, the average acceleration rate and the minimum headway between vehicles. The first operation of the program is to calculate the average headway between vehicles in seconds.

$$AVEHDY = 3600.0/VPH \qquad 3.1$$

where

AVEHDY = average headway in seconds,

VPH = traffic volume in vehicles per hour.

Next, the number of vehicles initially required to be on the road at the beginning of the simulation is calculated.

$$K = \text{VPH} * \text{DST} / \text{AVEVEL} \quad 3.2$$

where

K = the number of vehicles required to be on the road initially to simulate the desired traffic volume,
 VPH = traffic volume in vehicles per hour,
 DST = the length of road to be simulated,
 AVEVEL = the approximate average velocity of the vehicles in miles per hour.

Then a random number between 0.0 and 1.0 is assigned to VEH(I,2), (I = 1 to K). In the simulation program, these random numbers are used to distribute these initial vehicles into the system in a random order.

Next, the total number of vehicles to be prepared for the simulation is calculated.

$$\text{KARDS} = \text{VPH} + 100$$

where

KARDS = the total number of vehicles to be prepared for the simulation,
 VPH = traffic volume in vehicles per hour.

Subsequently, the remaining values of VEH(I,2), (I = K + 1 to KARDS) may be calculated. These values represent the times at which each individual vehicle will enter the simulated road. Headway between vehicle arrivals is

determined by the following equation:

$$X = \text{XMNHDY} - (\text{AVEHDY} - \text{XMNHDY}) * \text{ALOG}(\text{RAND}(0)) \quad 3.4$$

where

X = headway between consecutive vehicles in seconds,
 XMNHDY = the minimum headway allowed between vehicles
 (2 seconds),

$\text{ALOG}(\text{RAND}(0))$ = logarithm of a random number between
 0.0 and 1.0.

The resulting vehicle arrival rate follows a translated Poisson distribution (25).

With these operations complete, the program proceeds to assign values to the remainder of the vehicle data matrix. First, $\text{VEH}(I,1)$, ($I = 1$ to KARDS) is randomly assigned the value of 1.0 or 0.0. The assignment of a 0.0 means the vehicle enters the simulation system in the right lane while the assignment of a 1.0 means the vehicle enters the simulation system in the left lane. Next, $\text{VEH}(I,3)$, ($I = 1$ to KARDS) is assigned a value by the function subprogram $\text{SPEED}(X)$. Function subprogram $\text{SPEED}(X)$ draws a random number to determine the desired speed for the vehicle from a distribution of observed speeds. This distribution of speeds (Figure 3.1) was taken from the average distribution of observed speeds on ten primary two-lane rural highways in Missouri (26). Subsequently, $\text{VEH}(I,4)$, ($I = 1$ to KARDS), the actual vehicle speed is set equal to $\text{VEH}(I,3)$, ($I = 1$ to KARDS), the previously determined

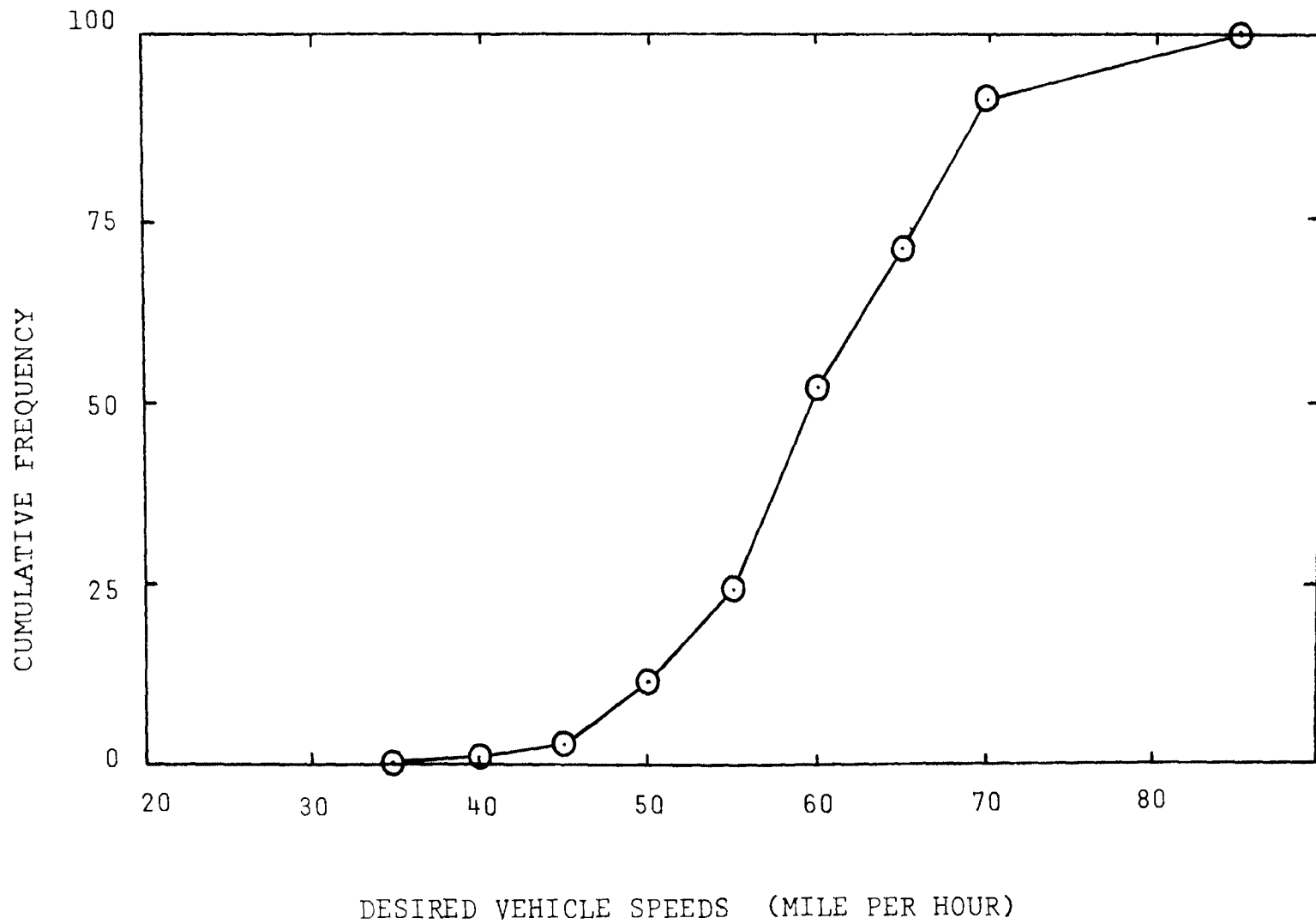


FIGURE 3.1 - CUMULATIVE SPEED DISTRIBUTION

desired speed, meaning that the vehicles will enter the simulating system traveling at their desired speed.

VEH(I,5), (I = 1 to KARDS) is assigned the value of 0.0. This variable is used later by the simulation program in determining whether a pass has been completed. But, it must first be initially set equal to zero.

Following this, VEH(I,6), (I = 1 to KARDS) is assigned a value for its acceleration rate according to the following equation:

$$\text{VEH}(I,6) = \text{ACC} - .5 + \text{RAND}(0) \quad 3.5$$

where

VEH(I,6) = the acceleration rate of the individual vehicle,

ACC = the average acceleration rate established at the beginning of the program (3 ft./sec.²) (27),

RAND(0) = a random number between 0.0 and 1.0.

Acceleration rates assigned in this manner results in the individual acceleration rates being distributed according to a uniform random distribution between ACC - .5 and ACC + .5 in feet per second squared (28). A fixed value for deceleration rate (16 ft./sec.²) is assigned to VEH(I,7), (I = 1 to KARDS) (12).

The final step of the vehicle data preparation program is to punch the information contained in the vehicle data matrix onto IBM cards so that the cards may be read into the simulation program.

The second data preparation program assigns the location of the no-passing zones along the simulated highway. Location of the no-passing zones is determined from a log-mile record of no-passing zones furnished by the Missouri State Highway Commission (29). These log-mile records were furnished for two typical rural highways in Missouri with approximately 34% and 67% no-passing zones.

Beginning and ending log-mile of each no-passing zone is punched onto IBM cards. When these cards are read into the simulation program, the log-mile record of no-passing zones is converted to a unit block record of no-passing zones by assigning a distinctive value to unit blocks that are within no-passing zones.

C. Main Program

The main line program has the following six major functions:

1. Initializing the variables.
2. Entering vehicles into the simulating system.
3. Advancing all vehicles along the road except those performing a passing maneuver.
4. Calculating the relative location and speed of vehicles and feeding this information into the subroutine which makes the decision on whether to pass or delay.
5. Slowing vehicles to maintain a proper following distance when a pass may not be attempted.
6. Printing output statistics.

The primary step in initializing variables is reading in the two major matrixes: IUB(I,J) the road configuration matrix, and VEH(I,J) the vehicle data matrix. This includes the random placement of a predetermined number of vehicles throughout the system according to a uniform probability distribution. The number and placement of vehicles is predetermined by the vehicle data preparation program so as to simulate a given traffic volume.

The secondary step in initializing variables is to assign initial values to the various parameters. These parameters include:

VPH = traffic volume in vehicles per hour,
 SIMTIM = maximum simulation time, (seconds)
 SIMDST = length of the simulation road, (miles)
 LUB = length of a unit block (20 feet),
 TIME = simulation time, (seconds)
 ITV = time increment (2 seconds),
 NOA = number of arrivals,
 NOP = number of passes,
 DLYTIM = delay time, (seconds)
 LEAVE = number of vehicles leaving the system
 IM = emergency indicators,
 SPACE = the space required for vehicle to return to
 its original lane to complete a passing maneuver,
 (feet)
 NUB = (SIMDST * 5280.0)/LUB
 = Number of unit blocks

Entering vehicles into the system at the correct time is the second major function of the main line program. If TIME is less than or equal to the time of the next arrival, the program enters the next vehicle into the system. Each time interval this check is made to determine if it is time for another arrival.

Vehicles are advanced along the simulated road by moving the vehicle through a series of unit blocks. The program scans each unit block along the simulated highway at every time interval. If a vehicle is present, the program checks to determine if the vehicle is performing a passing maneuver. When the vehicle is performing a passing maneuver, the main program calls the proper passing subroutine (PASSR for the right lane and PASSL for the left lane). However, if the vehicle is not performing a passing maneuver, the main program calculates the vehicles new location after traveling a time interval at its desired speed. Next, the program determines whether the actual following distance at this desired speed is greater than required following distance F.

$$F = VNV / (XLUB * 1.47) \quad 3.6$$

where

F = the required safe following distance,

VNV = the velocity of the vehicle being followed,

XLUB = length of a unit block.

Equation (3.6) has the effect of requiring ten feet of following distance for every ten miles per hour of speed

(27). Should the actual following distance be greater than the required following distance, the vehicle is placed in this new location until the next time interval. However, if this following distance rule would be violated by placing the vehicle in its desired new location, a decision as to whether to initiate the passing maneuver must be made.

Before calling the decision to pass subroutine \$PASS, the relative location and speed of all the vehicles involved in the passing maneuver is determined. This relative location and speed information consists of:

ACC = acceleration rate of vehicle desiring to pass,
 VEL = velocity of vehicle desiring to pass, (ft./sec.)
 XLAG = distance from vehicle desiring to pass to the
 vehicle being passed, (feet)
 VNV = velocity of vehicle being passed, (ft./sec.)
 XDTG = distance from vehicle desiring to pass to an
 opening in its original lane where the pass may
 be completed, (feet)
 GAP = distance from vehicle desiring to pass to the
 closest oncoming vehicle in the opposite lane,
 VOC = velocity of oncoming vehicle, (ft./sec.)
 XLPZ = distance from vehicle desiring to pass to the
 beginning of the next no-passing zone. (feet)

Using this information the decision to pass subroutine, \$PASS, determines whether to attempt a pass.

A decision to attempt a passing maneuver results in the main program calling PASSR for vehicles in the right

lane and PAssL for vehicles in the left lane. These subroutines move the vehicle through the passing maneuver. However, if the decision is to not attempt a passing maneuver, the main program slows the vehicle to maintain a proper following distance. When this slow down is necessary, an increase in delay time is recorded.

The final function of the main line program is to output information as desired. Printing output information may be done in two different ways.

1. Output information throughout the simulation run whenever a significant event occurs. This means that all arrivals, departures, attempted passes, emergency indicators and increases in delay time are printed when they occur.
2. Output information only at the end of the simulation run. This method saves some computer time but does not allow for a detailed analysis of the simulation run.

D. \$PASS

\$PASS is the subroutine responsible for determining whether to initiate a passing maneuver. This subroutine is called whenever a vehicle will be constrained to travel at less than its desired speed because of a leading vehicle, and the vehicle desiring to pass is in a passing zone. Subroutine \$PASS only determines whether to initiate a passing maneuver and does not move the vehicle through the passing maneuver.

Several different sets of criteria, or passing rules, for initiating the passing maneuver have been developed to determine their effect on the output from the simulation.

These passing rules are as follows:

1. Pass Everytime. Everytime a vehicle would be forced to slow down because of a leading vehicle, it attempts to execute a flying pass. Using this passing rule creates the maximum number of passes and emergency indicators.
2. Pass Only When it is Safe to Pass. This passing rule means that a passing maneuver will be initiated only when the passing vehicle will remain in a passing zone throughout the passing maneuver, there is a sufficient gap in the right lane for the passing vehicle to return to its own lane after completion of the pass, and the gap between the passing vehicle and the closest oncoming vehicle in the opposite lane is long enough to make a safe pass physically possible. Using this method to initiate the passing maneuver removes driver judgement and human error and provides the maximum number of safe passes.
3. Various Gap Acceptance Criteria. Using this passing rule a vehicle will accept a passing opportunity only if a predetermined gap between passing vehicle and the closest oncoming vehicle in the opposite lane is available. Acceptable gaps may

be any fixed value, or the vehicle may accept gaps according to probability distributions with the parameters of gap to oncoming vehicle and the speed of the leading vehicle (20). By examining the effects of these various gap acceptance parameters, it is possible to determine if gap acceptance is a significant factor in the overall flow characteristics of a two-lane rural highway.

E. PASSR and PASSL

Subroutines PASSR and PASSL are responsible for advancing vehicles through the passing maneuver. PASSR moves vehicles in the right lane. PASSL moves vehicles in the left lane. All vehicles accelerate uniformly for a full time interval when the passing maneuver is initiated. The new velocity of the passing vehicle and distance traveled by the passing vehicle are determined by the following equations:

$$\text{VEH}(K,4)_{\text{NEW}} = \text{VEH}(K,4)_{\text{OLD}} + \text{VEH}(K,6)*\text{XITV} \quad 3.7$$

where

$\text{VEH}(K,4)_{\text{NEW}}$ = velocity (ft./sec.) of the vehicle performing the passing maneuver after one time interval of acceleration,

$\text{VEH}(K,4)_{\text{OLD}}$ = velocity (ft./sec.) of the passing vehicle before one time interval of acceleration,

VEH(K,6) = individual acceleration rate (ft./sec.²) of the passing vehicle established by the data preparation program,

XITV = the length of one time interval in seconds.

and

$$AD = (VEH(K,4)*XITV + VEH(K,6)*(XITV**2)/(2.0))/XLUB$$

3.8

where

AD = the number of unit blocks traveled during one time interval of uniform acceleration,

VEH(K,4) = present velocity (ft./sec.) of the passing vehicle,

VEH(K,6) = individual acceleration rate (ft./sec.²) of the passing vehicle established by the data preparation program,

XITV = the length of one time interval in seconds,

XLUB = length of one unit block in feet.

Passing vehicles continue to accelerate uniformly each time interval until the velocity of the passing vehicle is equal to or greater than the velocity of the vehicle being passed plus ten miles per hour. This modeling of the passing maneuver is in agreement with AASHO design standards. In the AASHO design standards, the passing vehicle is assumed to average ten miles per hour faster than the vehicle being passed (1, 2). After the passing vehicle has reached

this maximum speed for the passing maneuver, the passing vehicle is advanced at this maximum speed until the passing maneuver is terminated.

There are two ways a passing maneuver may be terminated. Each time interval a check is made to determine if the passing vehicle may safely return to its original lane and complete the passing maneuver. To safely complete a pass in this manner, the passing vehicle must have passed the vehicle that it was previously following, and a space of 150 feet (13) must be available to allow the passing vehicle to return to its original lane. Whenever a pass is terminated in this manner a completed pass is recorded.

Additionally a check is made at each time interval to determine if it is necessary to terminate or abort the passing maneuver in order to avoid a collision. The next position of the passing vehicle is compared to the next location of the closest oncoming vehicle. If the next positions of the two closing vehicles are within 40 feet of each other, collision is imminent and the passing attempt is terminated. Whenever a pass is terminated in this manner, an emergency indicator is recorded and the vehicle attempting to pass swerves back into its original lane. An emergency indicator does not mean that a collision has occurred, however an emergency indicator does mean that the passing attempt could not be completed with an acceptable margin of safety.

F. Explanation of Output

The following output statistics and messages are printed by the simulation program:

NOA = number of arrivals.

This is printed each time a new vehicle enters the system, along with the time of the arrival, a code indicating whether the vehicle enters the right or left lane and the vehicle number.

LEAVE = number of departures.

This is printed each time a vehicle leaves the system, along with the number of the vehicle leaving the system and the time of departure.

NOP = number of passes.

This is printed each time a passing maneuver is attempted. Also printed at this time is the number of the vehicle attempting to pass and the time of the passing attempt.

PASS COMPLETE

This message is printed each time a passing maneuver is safely completed. Also printed at this time is the number of the vehicle safely completing the pass.

EMER IND = number of emergency indicators.

This is printed each time a passing maneuver is terminated because the attempted pass may not be completed with an adequate

margin of safety. Also the time that the pass is terminated is printed at this time.

DELAY TIME = total number of seconds that vehicles are forced to travel at less than their desired speed because of a slower leading vehicle.

This is printed each time the total delay time is increased. Additionally, the number of the vehicle being delayed, and the lane in which the delay occurs is printed.

It is not necessary to output all of these variables each time one of the specific events occurs. However, by having this information printed each time a significant event occurs, it is possible to better analyze the simulation to determine if the model is performing as expected.

IV. RESULTS AND DISCUSSION

A. Pass Everytime

Computer runs using the "pass everytime" passing rule were made to determine at what traffic volume a significant number of potential passing conflicts begin to occur. By requiring a vehicle to pass, rather than slow down, everytime it overtook a slower vehicle, the maximum number of passes and emergency indicators were generated. This passing rule simulates the situation where a driver attempts to pass regardless of oncoming traffic or sight distance restrictions.

From the output of these simulation runs (Table 4.1), it may be seen that no passes were required at or below traffic volumes of 60 vehicles per hour, and that no emergency indicators were generated at or below 80 vehicles per hour. These results indicate that no passing situations would occur for traffic volumes of 60 VPH or less, and no conflicts with oncoming vehicles would occur for traffic volumes of 80 VPH or less, even if a driver were foolish enough to pass without regard for his own and others safety everytime a passing situation arose. These results should not be taken to mean that passing attempts or conflicts with oncoming vehicles may not occur at traffic volumes less than those indicated. But, these simulation runs do indicate that passing attempts and conflicts with oncoming vehicles are extremely rare events at these low traffic

volumes and that the probability of such events approaches zero at the indicated traffic volumes for the particular speed distribution used in this model.

Figure 4.1 shows graphically the number of attempted passes versus traffic volume and the number of emergency indicators versus traffic volume from simulation runs using the "pass everytime" passing rule. These graphs show that the rate of change for both attempted passes and emergency indicators versus traffic volume begins to increase in the general region of 100 vehicles per hour.

Figure 4.2 and figure 4.3 show curves that were fitted to the data points, between 100 and 800 VPH, using the method of least squares. Equation 4.1 expresses the number of attempted passes as a power function of traffic volume, and equation 4.2 expresses the number of emergency indicators as a power function of traffic volume. A correlation coefficient of .99 was obtained using a least squares fit for these curves.

$$\text{NOP} = .00142 * \text{VPH}^{**1.90} \quad 4.1$$

$$\text{IM} = .00000378 * \text{VPH}^{**2.76} \quad 4.2$$

where

NOP = number of passes generated when the "pass everytime" passing rule is used,

IM = number of emergency indicators generated when the "pass everytime" passing rule is used,

VPH = traffic volume in vehicles per hour.

B. Pass Only When Safe to Pass

Computer runs using the "pass only when safe to pass" passing rule were made to determine what effect the removing of human error had on the simulation output. This passing rule was also used to determine if the simulation model was performing as desired. Using this passing rule means that a passing maneuver is initiated only when: (a) the passing vehicle will remain in a passing zone throughout the maneuver, (b) there is a sufficient gap in the right lane for the passing vehicle to return to its own lane after completion of the pass, and (c) the gap between the passing vehicle and the closest oncoming vehicle in the opposite lane is long enough to make a safe pass physically possible.

Output from these simulation runs (Table 4.2) indicates the maximum number of safe passes and the amount of delay time that occurs for various traffic volumes and various road geometries. This maximum number of safe passes indicates only the number of passes attempted where the driver was able to determine before he initiated a passing maneuver that it was safe to perform that passing maneuver. Often, the driver cannot determine if it is safe to pass because of limited sight distance. When sight distance is limited, many opportunities to pass safely are missed because the driver cannot see far enough to determine that it is safe to pass. For purposes of this simulation, sight distance was limited by allowing the driver to see 300 feet

into the next no-passing zone. The amount of delay time indicates the total number of seconds that vehicles were forced to travel at less than their desired speed because of a slower leading vehicle.

From the data (Table 4.2) it may be seen that no passes were attempted when 67% no-passing zones were used. This result is due to the particular configuration of these no-passing zones used in this model. The configuration of these no-passing zones was taken directly from the log-mile record of no-passing zones for a rural road consisting of a series of short hills and curves, typical of many roads in the Missouri Ozarks. Although only 67 percent of the simulated road was striped as no-passing zones, the distance between the no-passing zones was usually short, less than 1000 feet, because of the many short hills and curves. With the speed distribution used in this simulation, virtually all passes are high speed passes (2) requiring more than 1300 feet sight distance.

Figures 4.4 and 4.5 show graphically the relationship between attempted passes and traffic volume and the relationship between delay time and traffic volume for simulation runs using the "pass only when safe to pass" passing rule. From figure 4.4, it may be seen that the number of passes increases with traffic volume until the traffic volume reaches approximately 800 vehicles per hour. If traffic volume increases beyond region of 800 vehicles per hour, the number of passes generated decreases with

increasing traffic volume. Figure 4.5 shows that after the maximum number of passes have been generated in the region of 800 vehicles per hour, the amount of delay time generated increases linearly with increasing traffic volumes through 1200 vehicles per hour.

C. Effect of Various Gap Acceptance Criteria

Computer runs were made using three different sets of criteria for gap acceptance to determine if gap acceptance is a significant factor in the overall traffic flow characteristics of a two-lane highway. The first criterion used for gap acceptance was to accept any gap greater than 1000 feet. This criterion was used to determine the effect of a constant value for gap acceptance and to compare the results with results from simulation runs using different gap acceptance criteria.

The second set of criteria used to determine gap acceptance was similar to that used by Cassel and Janoff in their simulation model (20). Using this gap acceptance criteria, the acceptable gap was determined according to a probability distribution which had as the only parameter the distance to an oncoming vehicle. Cassel and Janoff used an additional parameter of lead car speed to model the lower speed passing maneuver. However, it was possible to use only one parameter in this simulation model because the lead car speed was greater than 45 miles per hour in virtually all passing situations due to the faster speed distribution used in this model. According to studies made

by the Franklin Research Institute (7), the probability curves used by Cassel and Janoff reflect actual driver behavior on rural two-lane highways. Figure 4.6 shows the probability distribution similar to Cassel and Janoff's used in this model, as well as the probability distribution used by the third set of gap acceptance criteria.

The third set of gap acceptance criteria used another simple probability distribution to determine an acceptable gap. Using this distribution the acceptable gap is determined by the following equation:

$$\text{ACCGAP} = 1000 + 1000 * \text{RAND}(0) \quad 4.3$$

where

ACCGAP = length of an acceptable gap in feet,

RAND(0) = a random number between 0.0 and 1.0.

This equation results in the length of acceptable gaps being distributed according to a uniform random distribution between 1000 and 2000 feet. The third set of gap acceptance criteria was developed to determine if output similar to output generated using Cassel and Janoff's gap acceptance criteria could be generated by using a more simplified gap acceptance model.

Tables 4.3, 4.4 and 4.5 show the output from these simulation runs for various traffic volumes and various no-passing zone configurations. For simulation runs using zero percent no-passing zones, the following comparisons may be noted:

1. The different gap acceptance criteria appeared to have little effect on the number of passes attempted.
2. Approximately the same number of emergency indicators were generated by using either the "accept 1000 feet" criterion or the Cassel and Janoff criteria. However, the computer runs using the "accept 1000 + 1000 * RAND(0)" criteria generated considerably fewer emergency indicators.
3. Using either the Cassel and Janoff criteria or the "accept 1000 + 1000 * RAND(0)" criteria resulted in approximately the same amount of delay time being generated, while using the "accept 1000 feet" criterion resulted in significantly less delay time being generated.

The following comparisons may be noted for simulation runs using the 34 percent and the 67 percent no-passing zones road configurations:

1. The "accept 1000 + 1000 * RAND(0)" criteria results in significantly less passing attempts than using the other two criteria which result in approximately the same number of passing attempts.
2. The "accept 1000 feet" criteria results in slightly less emergency indicators being generated than using the Cassel and Janoff criteria, while using

the "accept 1000 + 1000 * RAND(0)" passing criteria results in less than one half as many emergency indicators being generated.

3. Each gap acceptance criteria appears to generate a significantly different amount of delay time, with the "accept 1000 feet" criteria generating the least delay time and the "accept 1000 + 1000 * RAND(0)" generating the most delay time.

Several general trends are indicated by the output data from the simulation runs discussed above.

1. The model used to describe gap acceptance is more significant determining delay time and emergency indicators than in determining the number of attempted passes. However, gap acceptance may be critical in determining the number of attempted passes in some instances.
2. The model used to describe gap acceptance becomes more significant as traffic volumes increase.
3. The model used to describe gap acceptance becomes more significant as the percentage of no-passing zones increase.

TABLE 4.1
 OUTPUT FROM SIMULATION RUNS USING THE "PASS
 EVERYTIME" PASSING RULE

Traffic Volume in Vehicles Per Hour	Number of Passes Attempted Per Mile Per Hour	Number of Emergency Indicators Per Mile Per Hour
50	0	0
60	0	0
70	3	0
80	6	0
90	6.87	1.25
100	9	1
120	19.8	6
200	37.3	12
300	65.4	25.2
400	117.5	61.4
500	193	111
600	267	156
700	356	267
800	510	370

TABLE 4.2
 OUTPUT FROM SIMULATION RUNS USING THE
 "PASS ONLY WHEN SAFE TO PASS" PASSING RULE

Traffic Volume in Vehicles Per Hour	Number of Passes Attempted Per Mile Per Hour	Delay Time Per Mile Per Hour
0% No-Passing Zones		
100	9	66.7
200	26.7	227
400	66.7	1580
600	136.4	4710
700	146.97	9879.8
800	152.2	12904.4
1000	143	23233
1200	81.8	33890.9
34% No-Passing Zones		
100	0	949.3
200	4	3060
400	18.7	7650
600	30.6	14200
67% No-Passing Zones		
100	0	949.3
200	0	3160
400	0	8386.7
600	0	17029.3

TABLE 4.3

OUTPUT FROM SIMULATION RUNS USING THE
 "ACCEPT 1000 FEET" GAP ACCEPTANCE CRITERION

Traffic Volume in Vehicles Per Hour	Number of Passes Attempted Per Mile Per Hour	Number of Emergency Indicators Per Mile Per Hour	Delay Time Per Mile Per Hour
0% No-Passing Zones			
100	9.3	0	0
200	32	4	16
400	92	26.7	341
600	232	74.6	1100
34% No-Passing Zones			
100	5.3	1.3	245
200	29.4	4	414
400	92	40	1981.3
600	172	70.7	5522.7
67% No-Passing Zones			
100	4	0	362
200	16	4	1490
400	46.7	20	3922.7
600	84	30.7	9816

TABLE 4.4

OUTPUT FROM SIMULATION RUNS USING GAP ACCEPTANCE
 CRITERIA SIMILAR TO THAT USED BY CASSEL AND JANOFF

Traffic Volume in Vehicles Per Hour	Number of Passes Attempted Per Mile Per Hour	Number of Emergency Indicators Per Mile Per Hour	Delay Time Per Mile Per Hour
0% No-Passing Zones			
100	9.3	0	16
200	26.7	2.7	109
400	90.5	30.6	523
600	223	70.7	2080
34% No-Passing Zones			
100	6.7	2.7	218.7
200	29.4	5.33	850
400	92	36	3067
600	172	74.7	6693
67% No-Passing Zones			
100	3	0	509.3
200	20	6.7	2250.7
400	38.7	14.7	5149.3
600	85.3	45.3	11157.3

TABLE 4.5

OUTPUT FROM SIMULATION RUNS USING THE
 "ACCEPT 1000 + 1000*RAND (0)" GAP ACCEPTANCE CRITERIA

Traffic Volume in Vehicles Per Hour	Number of Passes Attempted Per Mile Per Hour	Number of Emergency Indicators Per Mile Per Hour	Delay Time Per Mile Per Hour
0% No-Passing Zones			
100	9.3	0	0
200	28	1.3	109
400	90.5	14.7	489
600	213.5	46.7	2000
34% No-Passing Zones			
100	5.3	0	277
200	25.3	4.0	1154.7
400	72	18.7	4293
600	113.3	29.3	8954.7
67% No-Passing Zones			
100	4	0	554
200	4	0	2768
400	21.3	8	6882.7
600	26.7	9.3	14776

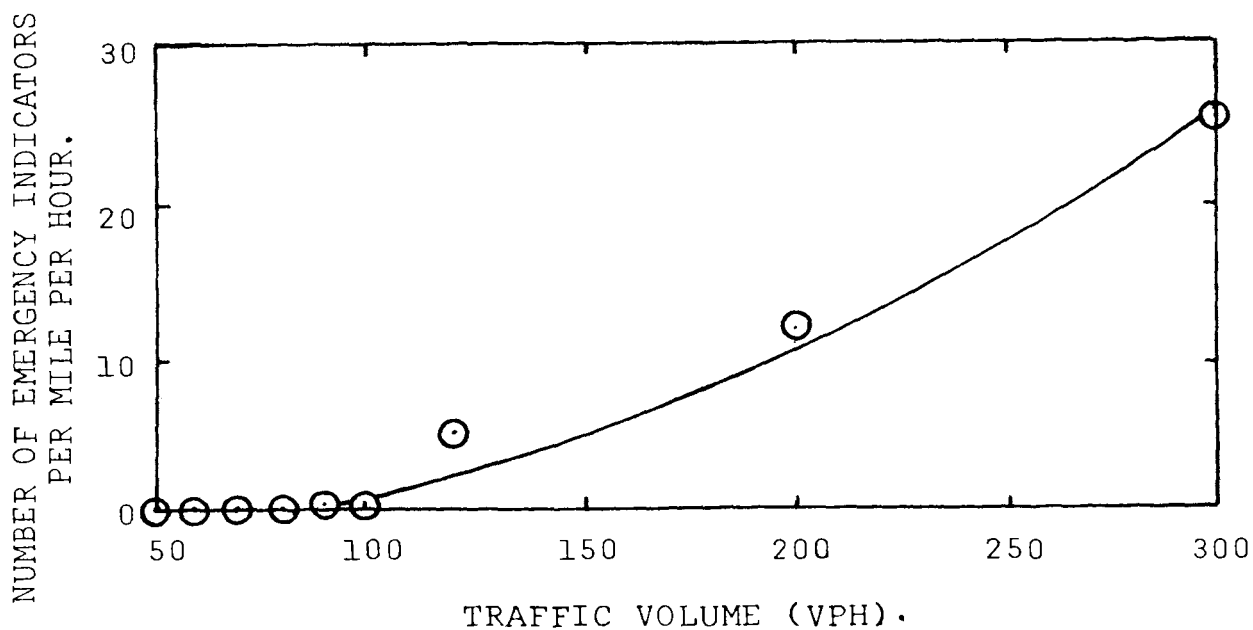
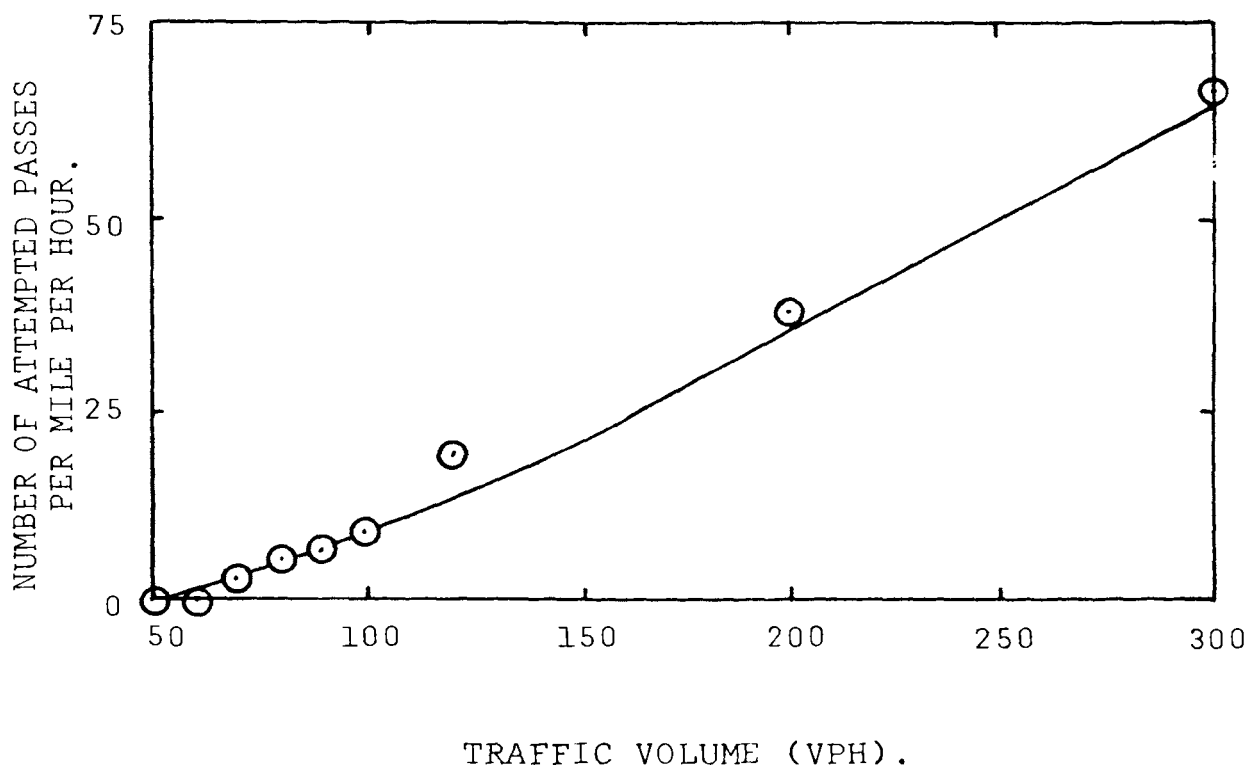


FIGURE 4.1 - TRAFFIC VOLUME VS. NUMBER OF ATTEMPTED PASSES AND TRAFFIC VOLUME VS. NUMBER OF EMERGENCY INDICATORS FOR LOW TRAFFIC VOLUMES WHEN THE "PASS EVERYTIME" PASSING RULE IS USED.

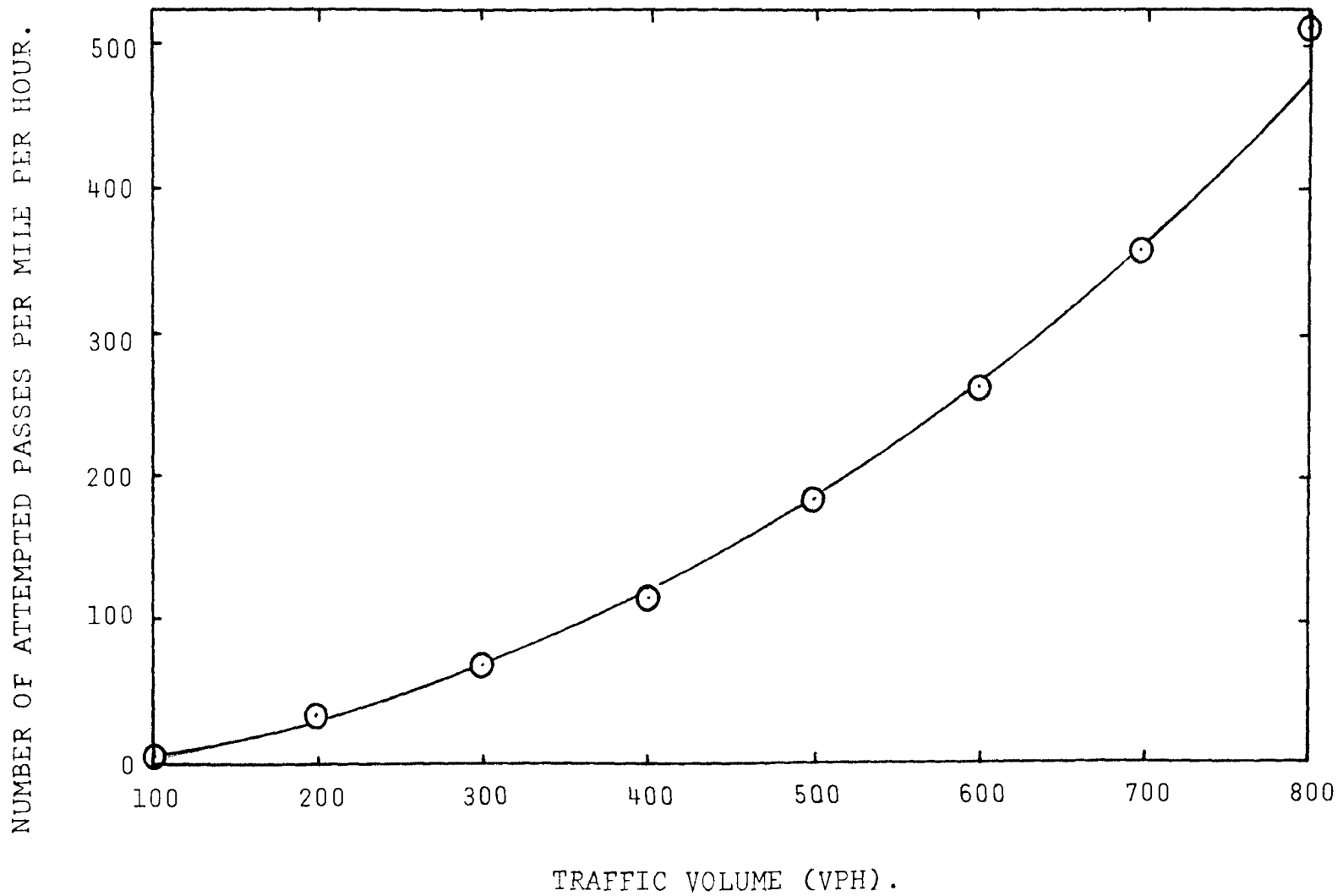


FIGURE 4.2 - TRAFFIC VOLUME VS. NUMBER OF ATTEMPTED PASSES FOR SIMULATION RUNS USING THE "PASS EVERYTIME" PASSING RULE.

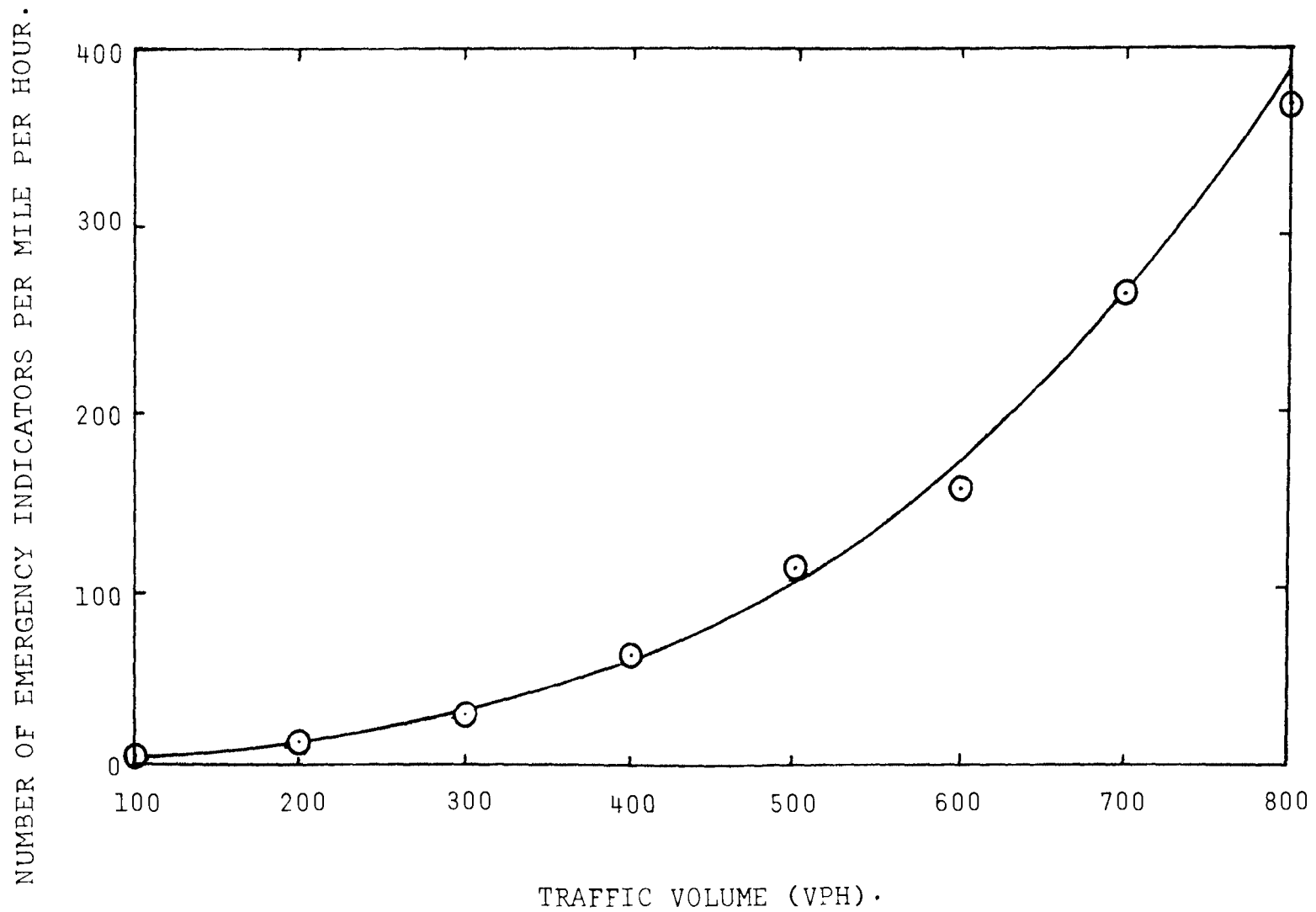


FIGURE 4.3 - TRAFFIC VOLUME VS. NUMBER OF EMERGENCY INDICATORS FOR SIMULATION RUNS USING THE "PASS EVERYTIME" PASSING RULE.

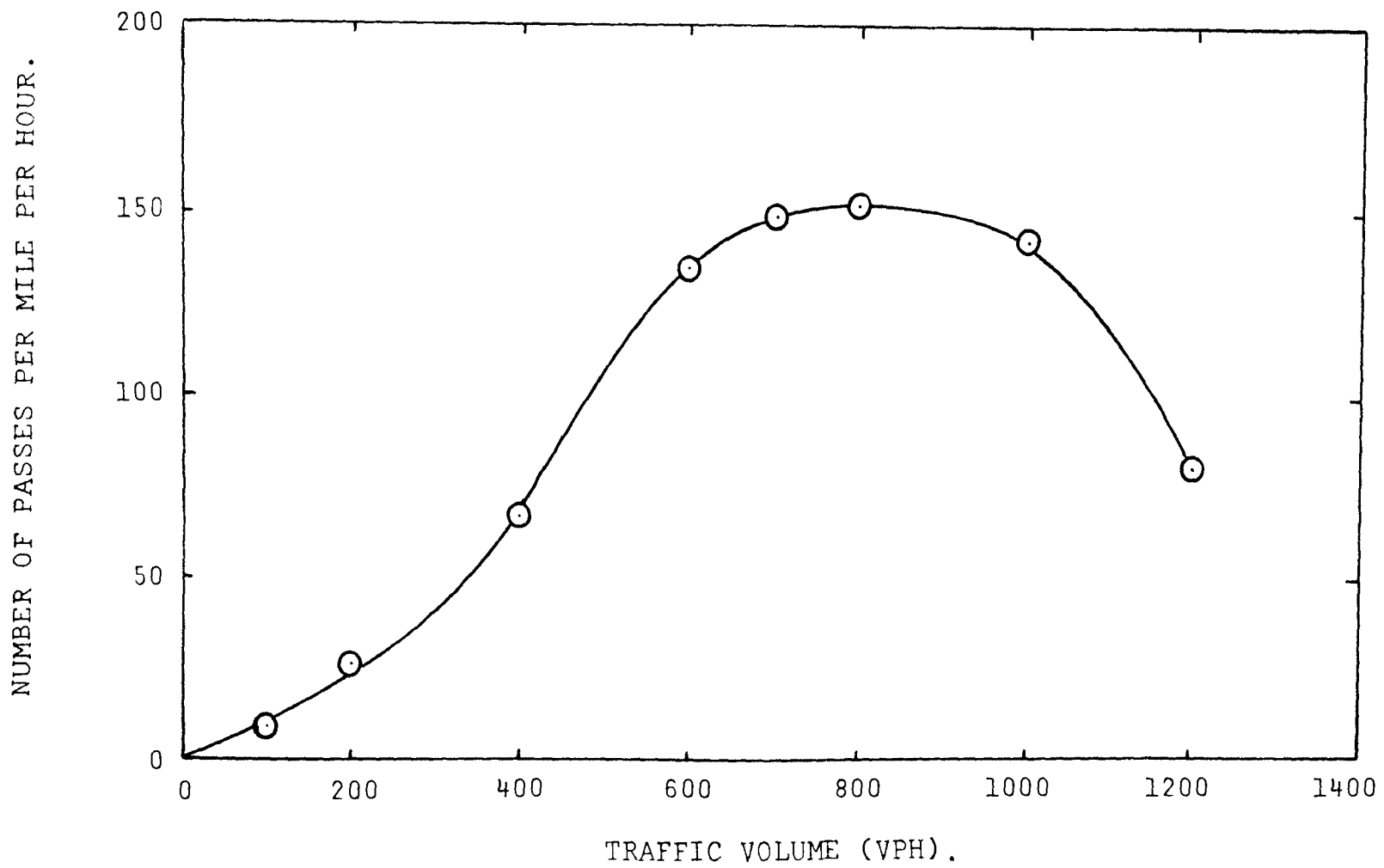


FIGURE 4.4 - TRAFFIC VOLUME VS. NUMBER OF PASSES FOR SIMULATION RUNS USING THE "PASS ONLY WHEN SAFE TO PASS" PASSING RULE.

TOTAL DELAY TIME PER MILE PER HOUR (SECONDS).

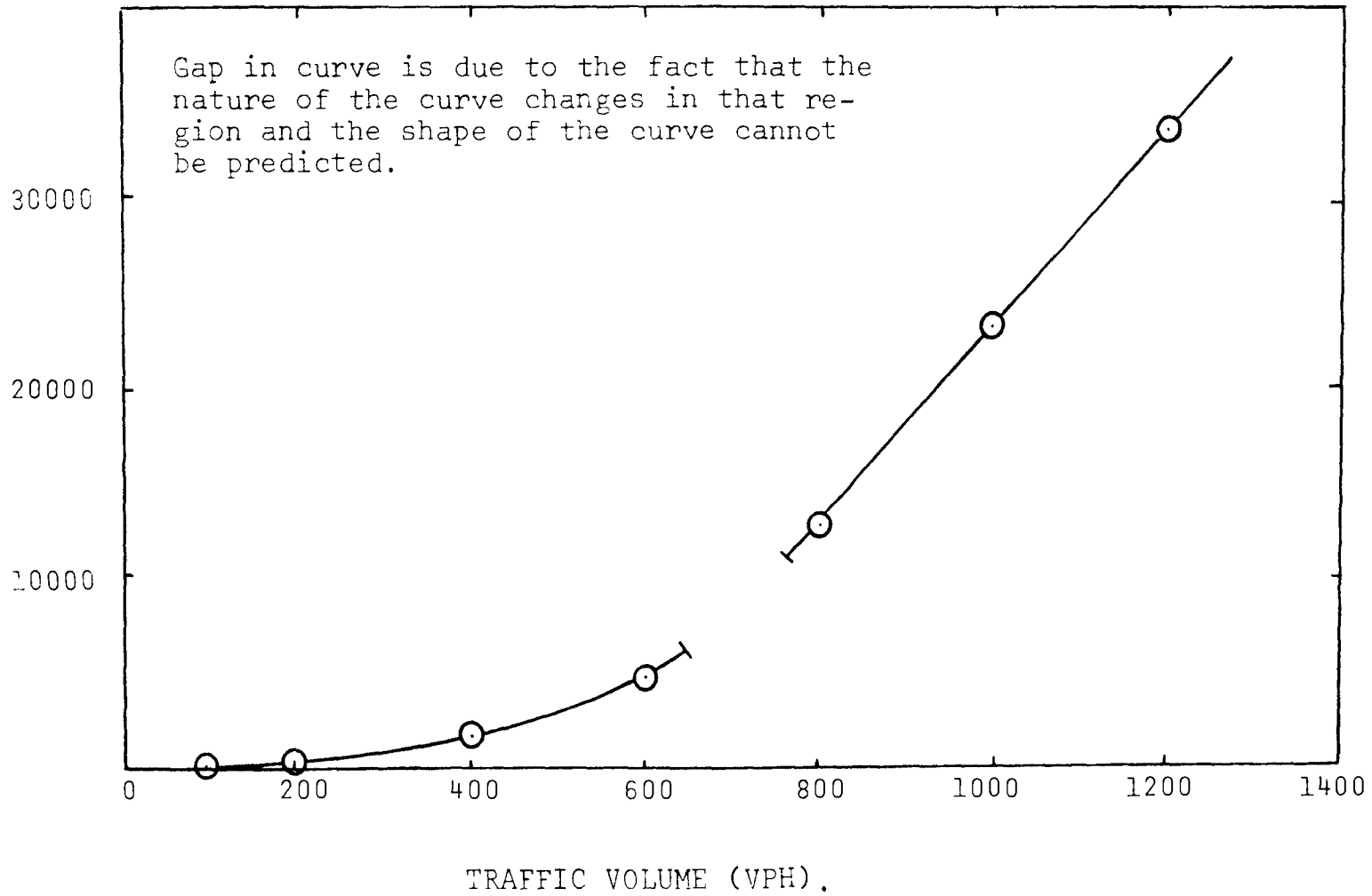


FIGURE 4.5 - TRAFFIC VOLUME VS. TOTAL DELAY TIME FOR SIMULATION RUNS USING THE "PASS ONLY WHEN SAFE TO PASS" PASSING RULE.

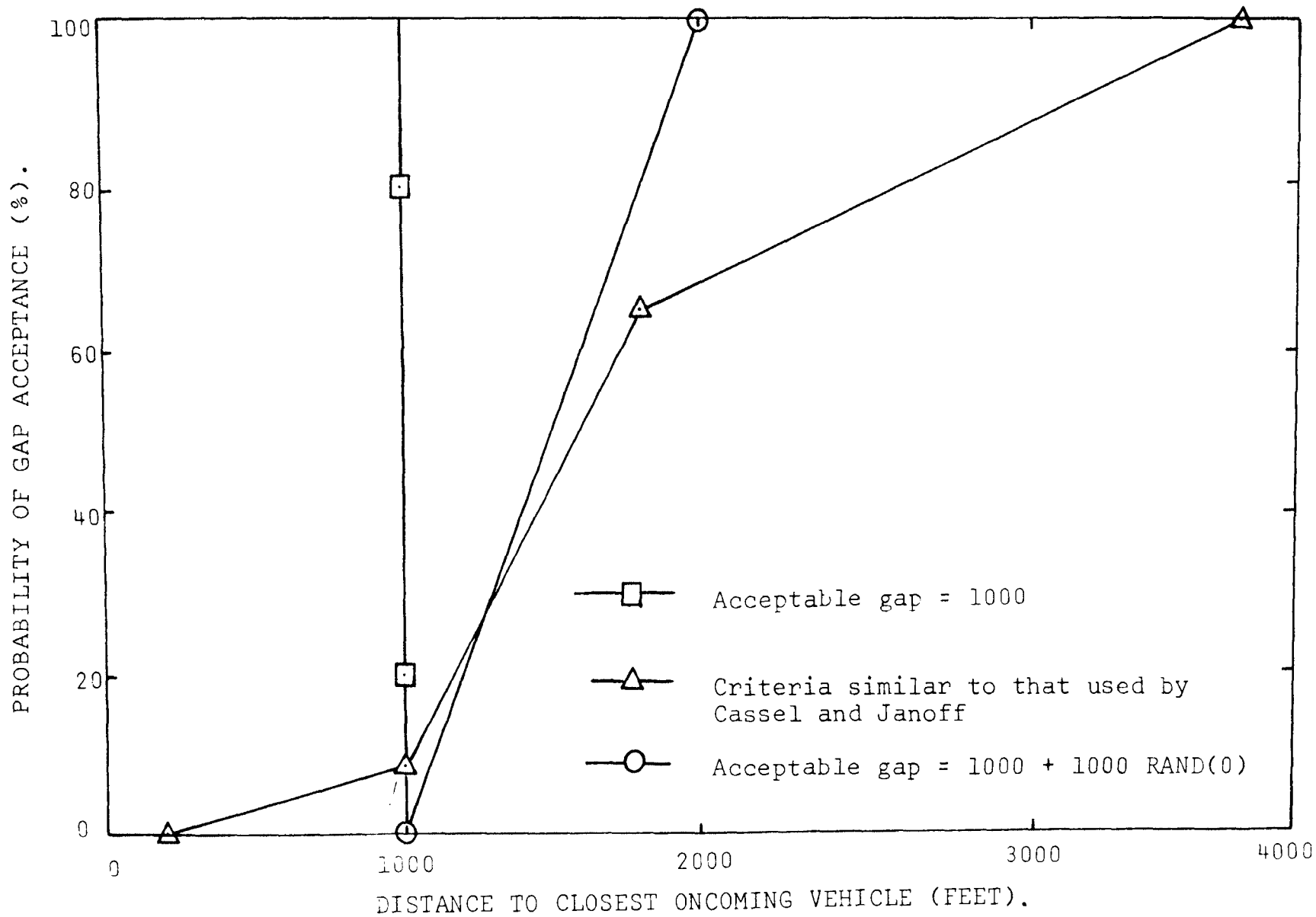


FIGURE 4.6 - GAP ACCEPTANCE CRITERIA.

V. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

Based on the results of this research the following conclusions may be made:

1. Assuming that maximum daily hourly traffic volume is approximately 10 percent of the average daily traffic volume, the results of this research indicate that the Missouri State Highway Department's use of 1000 ADT as a criterion for striping no-passing zones is a reasonable practice.
2. The number of attempted passes generated using the "pass everytime" passing rule may be expressed as a power function of traffic volume (Equation 4.1).
3. The number of emergency indicators generated using the "pass everytime" passing rule may be expressed as a power function of traffic volume (Equation 4.2).
4. If vehicles attempt to pass only when it is safe to pass, the number of passes increases with increasing traffic volume until traffic volume reaches 800 vehicles per hour. If traffic volumes increase beyond 800 vehicles per hour, the number of passes decreases with increasing traffic volume. As traffic volumes increase beyond 1000 vehicles per hour, the number of passes generated decreases rapidly with increasing traffic volume.

5. If vehicles attempt to pass only when it is safe to pass, the amount of delay time increases linearly with traffic volume as traffic volume increases beyond 800 vehicles per hour.
6. Output similar to the output generated using Cassel and Janoff gap acceptance criteria was not generated by using the more simplified gap acceptance model.
7. The model used to describe gap acceptance is more significant in determining the amount of delay time and the number of emergency indicators than in determining the number of attempted passes.
8. The simulation model becomes more sensitive to the modeling of gap acceptance as traffic volumes and the percentage of no-passing zones increase.

B. Recommendations For Further Research

1. It is recommended that this model be used to determine the effect of other speed distributions and other road configurations on the overall traffic flow on two-lane highway.
2. In this model, slow down factors were not used to simulate the effect of hills and curves. It is recommended that these factors be incorporated into the simulation model to determine their effect on overall traffic flow.

3. No attempt was made in this model to differentiate between passenger cars and trucks. It is recommended that the simulation model be modified to simulate the effect of trucks in order to quantify the effect of trucks on two-lane highways.
4. There is some controversy concerning the use of the long-zone concept of striping no-passing zones (2). It is recommended that the model be modified in order to compare the relative merits of the long-zone concept where the driver is allowed to cross a yellow line in his lane to complete a passing maneuver, and short-zone concept where the driver is not allowed to cross a yellow line in his lane at any time.
5. The results of this research indicate that gap acceptance is a significant factor in the overall traffic flow on two-lane highways. It is recommended that further studies be made to quantitatively describe the gap acceptance procedure.

BIBLIOGRAPHY

1. Hennes, Robert G., and Eske, Martin. Fundamentals of Transportation Engineering. New York: McGraw-Hill Book Company, pp. xiii, 1969.
2. Van Valkenburg, G. W., and Michael, Harold L. "Criteria for No-passing Zones." Prepared for presentation at the 1971 Annual Meeting of the Highway Research Board, Lafayette, Indiana, January, 1971.
3. U.S. Department of Transportation - Bureau of Public Roads Research and Development Report. Overtaking and Passing Under Adverse Visibility Conditions. 4 vols. Washington: Government Printing Office, vol. I, pp. 1, January 1970.
4. Weaver, Graeme D., and Glennon, John C. "Evaluation of Passing Sight Distance Design." Texas Transportation Researcher, vol. 6, number 3. Texas Transportation Institute, Texas A&M University, College Station, Texas, July 1970.
5. Norman, O. K. "Results of Highway Capacity Studies." Public Roads, vol. 23, no. 4. U.S. Bureau of Public Roads, June, 1942.
6. U.S. Department of Transportation - Bureau of Public Roads Research and Development Report. Identification and Evaluation of Remedial Aid Systems for Passing Maneuvers on Two-Lane Rural Roads. 5 vols. Washington: Government Printing Office, February 1970.

7. Silver, Carl A., Farber, Eugene, Weir, David H. and McRuer, Duane T. "Conceptualization of the Overtaking and Passing on 2-Lane Rural Roads." Franklin Institute Research Laboratories, Technical Report 1-193, May 1967.
8. McMillan, Claude, and Gonzalez, Richard F. Systems Analysis. Homewood, Illinois: Richard D. Irwin, Inc., pp. 23, 1968.
9. Hiller, Fredrick S., and Lieberman, Gerald J. Operations Research. San Francisco: Holden-Day, Inc., pp. 467, 1969.
10. Buhr, Johann H., Meserole, Thomas C., and Drew, Donald R. "A Digital Simulation Program of a Section of Freeway With Entrance and Exit Ramps." Highway Research Record, number 230, 1968.
11. Gerig, F. A. Class handout entitled "Simulation." November 1970.
12. Oglesby, Clarkson H. and Hewes, Laurence I. Highway Engineering. New York: John Wiley and Sons, Inc., 1963.
13. Matson, Theodore M., Smith, Wilbur S. and Hurd, Fredrick W. Traffic Engineering. New York: McGraw-Hill Book Company, Inc., 1955.
14. Jones, Howard V., and Heimstra, Norman W. "Ability of Drivers To Make Critical Passing Judgments." Highway Research Record, no. 122, pp. 91, 1966.

15. Gordon, Donald A., and Mast, Truman M. "Driver Decisions in Overtaking the Passing." Highway Research Record, no. 247, pp. 50, 1968.
16. Farber, Eugene, and Silver, Carl A. "Knowledge of Oncoming Car Speed as Determiner of Driver's Passing Behavior." Highway Research Record, no. 195, 1967.
17. Farber, Eugene, and Silver, Carl A. "Behavior of Driver's Performing a Flying Pass." Highway Research Record, no. 247, 1968.
18. Silver, Carl A., and Farber, Eugene. "Driver's Judgment in Overtaking Situations." Highway Research Record, no. 247, 1968.
19. Weaver, Graeme D., and Glennon, John C. "The Passing Maneuver As It Relates to Sight Distance Standards." Texas Transportation Institute, Texas Highway Department Cooperative Research Report, pp. ii, August 1968.
20. Cassel, Anno, and Janoff, Michael S. "A Simulation Model of a Two-Lane Rural Road." Highway Research Record, no. 257, 1965.
21. Erlander, S. "A Mathematical Model for Traffic on a Two-Lane Road." Proceedings of the Third International Symposium on Theory of Traffic Flow. Amr. Elsevier Publishing Company, pp. 153-167, 1967.

22. Fox, Phyllis, and Lehman, Fredrick B. "A Digital Simulation of Car Following and Overtaking." Highway Research Record, no. 199, 1967.
23. Dawson, R. F., and Michael, H. L. "Analysis of On-Ramp Capacities by Monte-Carlo Simulation." Highway Research Board, no. 118, 1966.
24. Gerlough, D. L., and Roland, R. D. "Improved Criteria for Traffic Signals at Individual Intersections." Highway Research Board NCHRP Report, no. 32, 1967.
25. Highway Capacity Manual. Highway Research Board Special Report 87, 1967.
26. Missouri State Highway Department. Unpublished speed distributions for ten rural two-lane highways in the Missouri primary system. December 1970.
27. Kern, Frank J. Personal Interview. March 1971.
28. Weinberg, Morton I., and Tharp, Kenneth J. "Application of Vehicle Operating Characteristics to Geometric Design and Traffic Conditions." Highway Research Board NCHRP Report, no. 68, 1969.
29. Missouri State Highway Department. Unpublished log-mile records of no-passing zones on two rural two-lane highways in the Missouri primary system. December 1970.

VITA

D. Jay Frankenfield was born July 20, 1948, in Springfield Missouri. He received his Bachelor of Science Degree in Civil Engineering from the University of Missouri-Rolla, in Rolla, Missouri, in May 1970.

He has been enrolled in the graduate school of the University of Missouri-Rolla since June 1970 and will receive his Master of Science Degree in Civil Engineering in May 1971.